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UN CDF CLEANSTART

ENERGY ACCESS AND OFF-GRID SOLAR USE IN UGANDA

EXAMINING SOLAR ADOPTION AND THE ROLE OF FLEXIBLE PAYMENT MECHANISMS AS A DRIVER FOR ENERGY ACCESS

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CONTENTS

ABBREVIATIONS AND ACRONYMS

AC	Alternating current
CGAP	Consultative Group to Assist the Poor
DC	Direct current
GOGLA	Global Off-Grid Lighting Association
LPG	Liquified petroleum gas
NPV	Net present value
PAYG	Pay as you go
PV	Photovoltaic
SACCO	Savings and Credit Cooperative Organization
SHS	Solar home system
SPL	Solar portable lamp
TXVA	Total transaction value (used in relation to mobile money transactions)
UNCDF	United Nations Capital Development Fund
W	Watt
Wh	Watt-hour
Wp	Peak watts (used in reference to solar module power ratings)

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AUTHORSHIP

This report was authored by Richa Goyal and Arne Jacobson from Schatz Energy Research Center. The views expressed in this publication are those of the authors and do not necessarily represent those of the United Nations, including UNCDF and their Member States or their partners.

KEYWORDS

Solar Energy Ladder; Solar Product Stacking; PAYGO, Digital Financial Inclusion

ABOUT UNCDF

UNCDF is the UN's capital investment agency for the world's 48 least developed countries. With its capital mandate and instruments, UNCDF offers "last mile" finance models that unlock public and private resources, especially at the domestic level, to reduce poverty and support local economic development. UNCDF's financing models work through two channels: financial inclusion that expands the opportunities for individuals, households, and small businesses to participate in the local economy, providing them with the tools they need to climb out of poverty and manage their financial lives; and by showing how localized investments — through fiscal decentralization, innovative municipal finance, and structured project finance — can drive public and private funding that underpins local economic expansion and sustainable development. By strengthening how finance works for poor people at the household, small enterprise, and local infrastructure levels, UNCDF contributes to SDG 1 on eradicating poverty and SDG 17 on the means of implementation. By identifying those market segments where innovative financing models can have transformational impact in helping to reach the last mile and address exclusion and inequalities of access, UNCDF contributes to a number of different SDGs.

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The UNCDF CleanStart Programme contributes to achieving SDG 7 on affordable and clean energy for all, and SDG8 focusing on decent inclusive work and economic growth and more specifically financial inclusion. The programme aims to drastically grow the access to clean energy finance for poor and low-income people. By partnering with energy and financial service providers and offering capital, data analytics, capacity building and policy advocacy services in the off-grid energy finance markets, UNCDF CleanStart has scaled energy business models for cleaner, efficient and more effective sources of energy for poor people. As of 2018, UNCDF CleanStart activities have resulted in over 220,000 low-income families and small-scale businesses accessing Renewable Energy Technologies (RETs) through micro and Paygo financing. UNCDF CleanStart is supported by the Austrian Development Cooperation, the Government of Lichtenstein, the Norwegian Agency for Development Cooperation (Norad), the UK Department for International Development (DFID), and the Swedish International Development Cooperation Agency (Sida).

ABOUT SCHATZ

The Schatz Energy Research Center (SERC) at Humboldt State University is located on California's North Coast. The Center engages in research and projects that support the establishment of clean and renewable energy in our society. Its areas of expertise include solar power, biomass energy, clean transportation, energy efficiency, and access to energy in off-grid areas. For the past decade, the Schatz Center has been an international leader in efforts to promote quality assurance and consumer protection in markets for off-grid solar products and systems. The Center's work involves research and development, technology demonstration, laboratory testing, feasibility studies, resource assessments, energy planning studies, energy systems analysis, and education and training.

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EXECUTIVE SUMMARY

Off-grid solar clean energy systems present a promising alternative to traditional fuels. In addition to providing superior lighting services, these systems can also power a variety of appliances. But what drives low-income customers to adopt such off-grid energy solutions? Can financing instruments such as pay-as-you-go (PAYG) plans play a supportive role in driving adoption? And to what extent can the purchase and use of PAYG solar systems drive digital financial inclusion?

To gain a better understanding of off-grid solar adoption patterns, we carried out a mixed-methods study in Uganda involving 554 households. Participating households had bought either a solar portable lamp (SPL) using cash, a mini-solar home system (SHS) using PAYG financing, or a larger SHS using micro-credit in 2015, and we tracked their energy product purchasing behaviour through early 2017. The study evaluated whether adoption followed an 'energy ladder' pattern[1] for solar products in which buying a small product (e.g. SPL) contributed to subsequent purchases of larger systems. It further investigated the role of flexible financing in aiding the adoption of solar products, and the extent to which the purchase and use of PAYG solar devices can contribute to increased digital financial inclusion.

The study used a combination of telephone customer surveys, comprising an initial survey (n=554) and follow-up survey conducted in two regions of Uganda between mid-2016 and early 2017 (n=498), and in-person customer interviews (n=105) conducted in the field. In addition, the study analysed data on mobile money transactions obtained from MTN Uganda for the customer sample (n=458). The research further draws on field observations about market conditions, and interviews conducted with retailers.[2] To fill in key details that influence adoption, we mapped locations of retail shops and collected other delivery chain details in the districts selected for the study (Section 4).

1 The concept of an 'energy ladder' adoption pattern for solar products borrows the term from earlier theories of an energy ladder for cooking fuel and technology adoption. The application of the energy ladder concept to cooking suggested that as households become more affluent, they abandon less efficient and more polluting cooking approaches such as wood and three-stone fires through a linear replacement process that leads to the adoption of improved biomass cookstoves and, eventually, modern fuels such as liquid petroleum gas (LPG) and electricity (Hosier and Dowd, 1987; Leach, 1988; Leach, 1992). The original energy ladder concept has been discredited in the academic literature as being overly simplistic, and it has been replaced with models of adoption such as fuel and technology stacking (e.g. Masera et al., 2000). Nonetheless, the term 'energy ladder' is still widely used, including in the off-grid solar sector, where it generally refers to the idea that the adoption of small off-grid solar products (e.g. solar lanterns) is an important first step towards the adoption of larger solar systems.

2 The methods for the study were reviewed and approved through the Institutional Review Board for the Protection of Human Subjects of Humboldt State University (approval code: IRB 15-017).

Key findings from the research include the following:

- **The solar energy ladder model does not describe off-grid solar adoption:** Among the Ugandan households in the study, we found little indication of an 'energy ladder' purchasing pattern. In fact, nearly all study participants, each of whom had purchased a solar-powered product or system in 2015, bought their first solar device when they made that purchase. This was true regardless of system size. This means that very few respondents who purchased an SHS or mini-SHS reported previously buying a smaller product such as an SPL.
- **Flexible payment mechanisms allow low-income households to adopt larger systems:** While the reported median income of buyers of larger SHSs was somewhat higher than that of the other respondents in the study, the median incomes of the buyers of mini-SHSs and SPLs were almost identical. Meanwhile, the level of energy service received, in watt-hours per day, was 10–40 times higher for the mini-SHS owners than for the SPL owners. This indicates that flexible payment terms (in the form of PAYG in this case) enabled rural Ugandans to access substantially higher levels of energy through mini-SHSs despite not having more income than SPL buyers.
- **Households that purchased small solar products experienced rapid economic payback, but those that purchased larger systems did not:** While owners of large SHSs and mini-SHSs received higher levels of energy service than owners of SPLs, they also paid much more for their systems. This was true overall (in gross investment terms) and also on a net present value (NPV) basis over two years after considering savings from avoided expenditures on things such as kerosene, candles, dry cell batteries and mobile phone charging. Buyers of SPLs experienced rapid economic payback and net savings over the two-year period, while SHS and mini-SHS buyers paid considerably more (between US$100 and US$735 depending on system size) than they recovered over that period. These latter buyers experienced an improved quality of life through enhanced energy access, but they did not achieve net financial savings.
- **Effective direct marketing drives adoption in greenfield markets:** The most important factor influencing the decision to adopt, according to respondents, was direct marketing and engagement from sales agents or entrepreneurs. Given the income parity mentioned above, for buyers of SPLs and mini-SHSs, direct marketing was more important than income for determining which products customers purchased. This suggests that rural Uganda has the characteristics of a greenfield market for off-grid solar products.
- **Some respondents made multiple solar product purchases, and many reduced or discontinued use of traditional fuels:** Many respondents in the study purchased multiple solar products over time in a bid to expand their electricity access. This purchasing pattern was especially prevalent for those who began by adopting SPLs. Additionally, after adopting solar products, end-users replaced traditional fuels and technologies, in part or in whole, with the solar-powered devices.
- **PAYG customers would prefer to make cash purchases:** Nearly all study participants (90 percent) who had purchased a product using the PAYG model indicated that they planned to make an additional purchase at the time of the initial survey, and 75 percent indicated that they would like to buy the product from the same company. However, none of the respondents wanted to use PAYG for their subsequent purchase. Instead, they preferred to buy using cash. This result may be linked to an awareness of the additional expense (by way of interest rates) incurred when a user opts for a financing plan and/or frustration

with the stress associated with the need to make frequent payments on a fixed schedule despite having a low income and uneven cash flow. There could be other explanations, including technical faults with the system and unsatisfactory support from the customer care team. There may be divergence between their apparent unwillingness to opt for PAYG financing in subsequent purchases and their ability to pay in full upfront. This topic would benefit from additional research.

- **Solar PAYG purchases did not seem to drive digital financial inclusion:** PAYG and non-PAYG customers reported using mobile money in similar ways and valuing it as a savings tool to approximately equal degrees. Furthermore, making solar payments was not a primary motivation for adopting mobile money accounts for PAYG customers, and most PAYG customers had mobile money prior to adopting PAYG solar. Thus, while digital financial inclusion in Uganda enables the adoption of solar products through PAYG, it is unlikely that PAYG by itself leads to expanded financial inclusion.

These findings do not support the idea that the adoption of small off-grid solar products such as SPLs is a necessary first step towards buying larger products such as SHSs. As we describe in greater detail below, they do indicate the important roles that flexible payment mechanisms and direct marketing play in influencing the adoption of off-grid solar technologies. It is important to note that the adoption patterns observed occurred in a relatively early-stage market, and markets with higher levels of market penetration, brand competition and consumer awareness may exhibit different patterns.

RECOMMENDATIONS FOR PRACTITIONERS

- **Invest in distribution:** Effective distribution chains, including direct marketing, are a key driver for the adoption of off-grid solar products in greenfield markets such as Uganda. If customers are likely to purchase from the first convincing sales agent they encounter, getting there first is the key to making a sale.
- **Know your customers and provide options:** The results of this study confirm that the purchase of small solar products may not be a necessary stepping stone towards the purchase of a larger off-grid solar system. Some customers may choose to buy a larger system if flexible payment mechanisms or other measures can make it affordable. Others may prefer to buy a smaller product because of the rapid economic payback it can offer, because they prefer to pay in cash or for other reasons. It can, therefore, be beneficial to offer customers a range of options regarding payment mechanisms and product size, performance and features, although this should be done within boundaries to avoid an overly complex sales and distribution operation.
- **Promote customer loyalty:** Many customers, including over 70 percent of those who purchased a mini-SHS or an SHS, indicated an interest in making a subsequent purchase from the same vendor. Given that customer acquisition is typically expensive, this indicates that investments in customer retention, including measures such as effective aftersales service, follow-up marketing and customer loyalty programmes, can represent a significant opportunity to promote additional sales.
- **When offering flexible payments, consider ways to reduce the payment burden on customers:** While flexible payment schemes such as PAYG can provide an effective mechanism to increase affordability and sales, the expressed preference for cash payments for subsequent purchases by PAYG and micro-credit customers suggests a level of dissatisfaction that should be evaluated and addressed.

RECOMMENDATIONS FOR FUTURE RESEARCH

- The value of the learnings from this study of customer adoption between 2015 and 2017 can be extended by continuing to track the purchasing behaviour of this group of off-grid solar users over time. A second round of follow-up phone surveys will be conducted to provide further insights into purchasing decisions.
- It would be valuable to complement the abovementioned phone surveys with in-person interviews with a subset of customers, focus group discussions with customers and/or interviews with energy service providers to explore key themes identified in the research. Topics of focus should include the reasons why customers expressed a preference for cash sales over flexible payment methods such as PAYG, measures that could be taken to overcome possible customer dissatisfaction with PAYG and micro-credit purchasing, and reasons for user (dis)satisfaction with solar products.
- A similar study of off-grid solar adoption patterns should be conducted in markets with different characteristics from Uganda's. For example, a temporal study of customer adoption in Kenya, which has a higher level of off-grid solar product adoption and greater levels of retail competition, would enable a useful point of comparison with findings from the current study. Similarly, a study in a market with relatively poor mobile money penetration in rural regions, such as India, would offer another useful point of comparison.
- Uganda recently enacted a mobile money transaction tax. It would be useful to determine whether this tax will negatively impact the use of mobile money, thereby affecting user willingness to make solar energy payments using mobile wallets. This could, in turn, hinder the adoption of PAYG solar products. Given the role that PAYG sales have played in enabling the adoption of small and larger SHSs, it is important to understand the role that such taxes may play in hampering adoption.

1 INTRODUCTION

Commercial sales of quality-assured off-grid solar products contribute to poverty alleviation and can serve as a gateway to modern energy access (Jacobson, 2004; Sovacool, 2012; Alstone, Gershenson and Kammen, 2015). Moreover, given the rise of mobile banking and pay-as-you-go (PAYG) sales models in the off-grid solar sector, some have suggested that solar products could contribute to increased digital financial inclusion (Winiecki, 2015; Waldron, 2016). Therefore, the recent rapid growth of off-grid solar sales in Africa and Asia, involving over 30 million quality-assured products sold since 2010 (Lighting Global, 2018a), is an encouraging vector for socio-economic development. Nonetheless, significant gaps remain in our collective understanding of the dynamics and significance of energy access through off-grid solar adoption. This study in Uganda addresses some of these gaps. This research focuses on investigating adoption patterns for off-grid solar products in rural Uganda, including an examination of factors that influence the adoption of products ranging from small solar portable lamps (SPLs) to larger solar home systems (SHSs). The research delves deeper to examine the role of flexible financing instruments in accelerating the adoption of off-grid solar technologies. The research also investigates the effectiveness of PAYG payment methods in expanding digital financial inclusion. In what follows we discuss the research questions under the study in greater depth.

RESEARCH QUESTIONS[3]

Question I: Does the solar energy ladder hypothesis or the fuel stacking hypothesis adequately explain how users adopt off-grid solar products? What are the factors that influence the adoption of off-grid solar technologies? What role do flexible payment mechanisms have in expanding the adoption of larger SHSs?

The term ‘energy ladder’ is often used to describe energy technology adoption processes that involve progression from traditional to modern fuels and devices. This adoption pattern was originally characterized as a linear progression, whereby users substitute inferior energy technologies with superior ones as their income increases and they move up the ladder. Although the energy ladder concept has been criticized and replaced in the academic literature by more nuanced frameworks such as energy technology stacking, in the off-grid solar sector, practitioners, policymakers and energy access programme designers often use the term ‘energy ladder’ to describe solar technology adoption patterns. Here, the ‘energy ladder’ framework has been translated into a specific ladder of off-grid solar products or the ‘solar energy ladder’. It refers to the idea that the purchase of small SPLs by off-grid households is an important first step towards purchasing larger off-grid solar products and systems. Under this concept, the expectation is that households ‘move up the solar ladder’ as

3 Note that literature citations are not included in the research questions section. References to the relevant literature sources can be found in the literature review section, below.

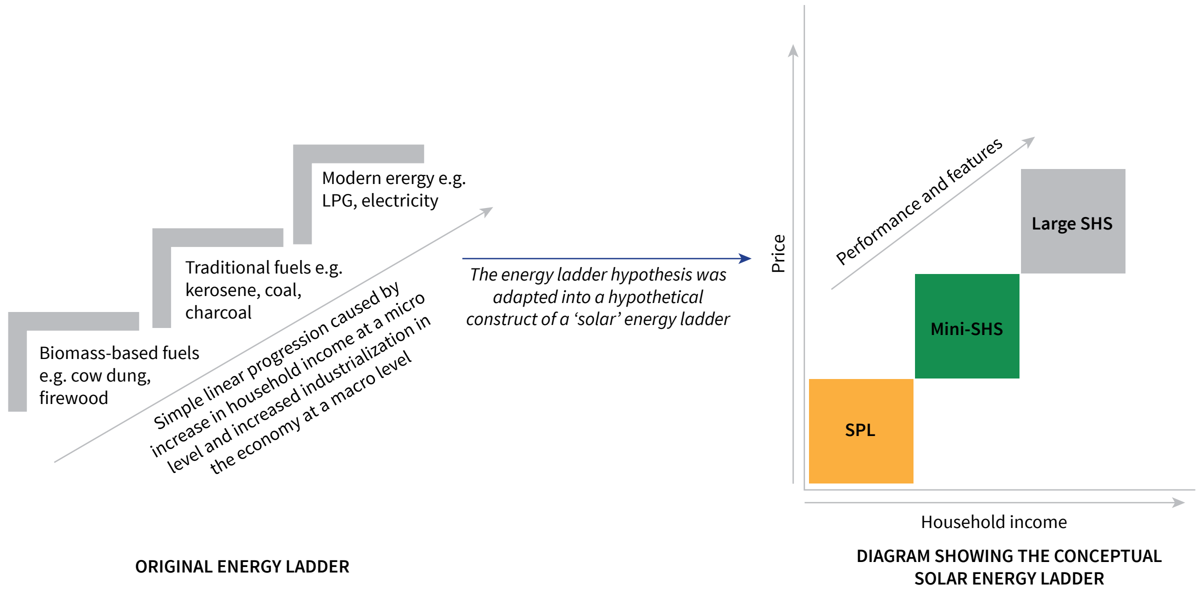

Figure 1. The original energy ladder has been adapted into the construct of a solar-specific energy ladder

income grows, by adopting successively larger off-grid solar products (Figure 1). While our observations indicate that people in off-grid areas generally adopt larger and more complex solar systems as they become available and affordable, we believe that the solar energy ladder does not provide the best analogy for describing the dynamics of off-grid solar product adoption. Given that the solar energy ladder concept is widely used in the off-grid solar sector, it is imperative to examine actual energy adoption patterns and their relationship to the solar energy ladder concept and other potential models of energy technology adoption.

A second hypothesis that has been used to explain the energy technology adoption process is the 'fuel stacking' hypothesis in which end-users continue to use more traditional fuels as they adopt more sophisticated fuels. If one were to adapt the 'fuel stacking' hypothesis to explain the adoption of solar products, an adoption behaviour where users use a mix of solar products as well as traditional fuels such as kerosene, candles, battery charging and others would be expected. The modularity in photovoltaic (PV) panel sizes and the wide range of solar products would also allow users to 'stack' different solar products to fulfil their energy demand by purchasing several products instead of a single solar system, leading to a 'solar-with-solar' stacking behaviour. We designed this research to examine solar technology adoption processes in rural Uganda to determine the degree to which concepts associated with the energy ladder and fuel stacking frameworks described these patterns, and also to gain an understanding of the factors that influence the adoption of off-grid solar technologies by rural Ugandans. We carefully examined the role of flexible payment options in expanding access to solar-based energy, and especially focus on understanding the ways in which emerging payment mechanisms such as PAYG can help expand the adoption of solar products.

Question II: Does PAYG financing of off-grid solar products help expand digital financial inclusion?

The expanded use of PAYG sales, including sales of SHS kits, mid-range pico-solar products that include mobile phone charging and new products sold through the 'Eco Easy Buy' approach announced by Greenlight Planet and Angaza, will further boost the diffusion of pico-solar products and help off-grid households and businesses expand access to solar energy. Many practitioners believe that making payments for solar devices using mobile wallets can help increase user comfort with mobile money financial services, thereby encouraging expanded use of a wider set of associated mobile money services such as savings and investment tools. To examine this issue, it is important to determine whether there is a clear connection between the use of PAYG solar devices and demand for mobile wallet services. According to findings of the FinScope III survey conducted by Bank of Uganda in 2013, 77 percent of the adult population are aware of mobile money services in Uganda, and 51 percent of the adult population are registered to use mobile wallet services (Findex 2017). This implies that for actual registration, being aware of mobile wallet services is not the limiting factor and that perhaps, if users were given a practical need to regularly use mobile money services, such as payment for solar devices, it could in theory lead to increased activity in user mobile wallets beyond just energy payments.

2 LITERATURE REVIEW

REVIEW OF EXISTING LITERATURE ON ENERGY FUEL AND TECHNOLOGY ADOPTION

Research on the topic of household energy use gained prominence during the oil crisis in the 1970s and a perceived fuelwood crisis caused by unsustainable deforestation in the 1970s and 1980s. It was during this time that the concept of the energy ladder was first suggested (Kowsari and Zerriffi, 2011; Taylor et al., 2011). The energy ladder model assumed that the end-user is a utility-maximizing neoclassical consumer and faces a 'ranked' or a 'preference-ordered' set of fuel choices, with biomass-based fuels ranked the lowest, and modern fuels such as liquefied petroleum gas (LPG) and electricity ranked the highest. This ranked set of choices was depicted in the shape of a ladder, and it was expected that the households, as economic agents, used the most sophisticated energy source that was affordable and available, switching up the ladder to more ideal energy sources as income increased (Masera, Saatkamp and Kammen, 2000; Kowsari and Zerriffi, 2011; Van Der Kroon, Brouwer and Van Beukering, 2013). In its simplest form, the energy ladder was described as a three-phase process, with the first phase being biomass-based fuels, the second being transitional fuels such as kerosene, coal and charcoal, and the third being modern energy options such as LPG, electricity and biofuels (Barnes, Krutilla and Hyde, 2004; Van Der Kroon, Brouwer and Van Beukering, 2013).

Over the past decade, small solar products that provide lighting and mobile phone charging services have become increasingly common (Lighting Global, Dalberg Associates and GOGLA, 2018). Today, off-grid solar systems can power a variety of super-efficient appliances and equipment for domestic, commercial and agricultural applications (Phadke et al., 2015). As the size of the solar system components, level of daily energy service and number of end-uses increase, the cost of the solar system generally goes up. It can be argued that the rational end-user, who is familiar with the benefits of off-grid solar technologies and is in proximity to a solar product retailer, *ceteris paribus*, will use the most sophisticated off-grid solar technology that is affordable to her or his household. Just like the original energy ladder, it becomes tempting to organize the range of commercially available solar products and systems into a hypothetical construct of a solar-specific energy ladder, expecting households to 'switch up the solar ladder' as increases in household income permit. A linear movement up the solar ladder by a household is a tempting hypothesis not only because higher-capacity solar products are more expensive, and so expanded energy access becomes a question of affordability, but also because solar-based energy devices are a modern technology, and a successful experience with a smaller solar product might help ease the perception of risk in investing in a bigger and more expensive, unfamiliar technology. However, before accepting the energy ladder model as a framework for understanding solar technology adoption patterns, it is important to study the criticisms of the model.

CRITICISM OF THE ENERGY LADDER MODEL

Over the past two decades, the energy ladder model has come under severe criticism by many energy scholars who have tested its validity. The criticism can be grouped into two main categories:

- The model had trouble accounting for multiple fuel use: The energy ladder concept of fuel and technology choice suggests that as end-users move up the ladder they completely abandon lower-ranked, inferior fuels. Several studies found this model to be weak. These studies indicate imperfect substitution of fuels and a 'fuel stacking' hypothesis in which end-users use multiple fuels and technologies to meet their needs, including continued use of traditional fuels and technologies in parallel with newer, more sophisticated ones (Masera, Saatkamp and Kammen, 2000; Wuyuan, Zerriffi and Jiahua, 2010; Nansaior et al., 2011)
- Other determinants for fuel choice: There can be numerous other influences on fuel choices than income, including supply-side constraints, such as national energy policies, infrastructure and the availability of modern fuels and appliances, and demand-side constraints, such as cultural preferences, awareness, education and others (Masera, Saatkamp and Kammen, 2000; Campbell et al., 2003; Barnes, Krutilla and Hyde, 2004; Heltberg, 2004; Lee, 2013)

Despite the criticism of the energy ladder model, the concept was adapted to describe the adoption of solar energy technologies for off-grid applications (Lighting Africa, 2012, 2014; A.T. Kearney and GOGLA, 2014; Guevara-Stone, 2015). According to this framework, buyers of 'entry-level' off-grid solar products such as small SPLs (which now typically have solar modules rated at 3W or less) will shift to larger and more powerful SHSs as their incomes rise and/or the price of solar products declines. The tiers of energy access in the multi-tier framework developed by the Sustainable Energy for All (SE4All) initiative in 2015 resembles the rungs of a ladder[4] and have lent further credibility to the existence of an off-grid solar energy ladder. In the context of this 'solar energy ladder' idea, users purchase larger SHSs after having purchased low-power solar devices first (Africa Progress Panel, 2015). As noted above, if one were to use a fuel and technology stacking hypothesis to explain the adoption of solar products, an adoption pattern characterized by a mix of technologies and fuels would be expected. The modularity in PV panel sizes and the wide range of solar products would also allow users to 'stack' several different solar products to fulfil their energy demand, instead of using a single solar system, leading to a 'solar-with-solar' stacking behaviour. This research explores each of these adoption theories: a) the solar energy ladder hypothesis; and b) the extent of solar and non-solar technology stacking and solar-with-solar stacking in 'Adoption patterns of off-grid solar energy technologies and factors that influence adoption' in Section 5.

LINKAGES BETWEEN DIGITAL SOLAR PAYMENTS AND DIGITAL FINANCIAL INCLUSION

The use of solar products and mobile devices in off-grid areas is deeply interconnected. Off-grid solar products are often used to charge mobile devices, thereby facilitating and reducing the cost of their use (Jacobson, 2004; Alstone, Gershenson and Kammen, 2015). Likewise, emerging business models for off-grid solar such as PAYG are strongly linked to the use of mobile money services (Winiecki and Kumar, 2014; CGAP, 2016). There are, therefore, well-known spillover benefits in both directions. Nonetheless, there are a number of outstanding questions associated with the relationship between off-grid solar adoption and digital financial inclusion. For example, does off-grid adoption commonly enhance digital financial inclusion, or is the reverse more likely to be true?

Several studies have tried to establish causality between the adoption of PAYG solar systems and increased digital financial inclusion. They

4 The SE4All multi-tier framework redefines energy access as a multidimensional measure which takes into account energy that is adequate, available when needed, reliable, of good quality, convenient, affordable, legal, healthy and safe.

do so by demonstrating 'additionality'—i.e. by showing that users adopt mobile money for the first time in order to use PAYG solar systems, that telecom companies experience increased revenue due to the use of a variety of mobile money services after establishing bill pay accounts with PAYG companies, and that users increase their transaction volume in mobile money accounts after investing in PAYG systems. While all these three aspects linked with the use of PAYG solar systems are true, it is unclear from such analyses whether there would still be a net increase in total transaction value in mobile money accounts of PAYG users if solar payments were removed, when compared with that of non-PAYG users. Furthermore, these studies do not talk about the use of services other than bill pay use via mobile money accounts—for instance, the use of financial services such as savings and investments, which are stronger indicators of financial inclusion.[5] Several factors can affect the adoption of mobile money accounts and mobile money transaction volumes. Some of these variables can affect the use of mobile money simultaneously. To attribute an impact on meaningful digital financial inclusion to the adoption of PAYG solar systems, it is necessary to isolate the effect of each factor to the degree possible and observe whether the use of digital services other than bill pay increased.

PAYG customers are often considered to be active mobile money users, as, for example, demonstrated in Uganda (GSMA, 2015) and Rwanda (GSMA, 2016). However, the studies do not clarify whether the increased activity was solely due to bill payments for PAYG systems or whether customers increased usage for other services. These studies also do not delve into other factors that may have influenced changes in the volume of mobile money transactions or determine whether the mobile money transaction behaviour of PAYG users differs significantly from that of non-PAYG users in a similar socio-economic bracket. CGAP (2016) argues that PAYG solar energy can drive the adoption of mobile money. Results from an informal survey of three leading PAYG solar companies operating in East Africa states that 30–50 percent of customers were 'new' mobile money users and that these solar companies were also some of the largest mobile money service providers. GSMA's report (2017) highlights that PAYG solar devices help increase mobile money account subscriptions, improve the digital literacy of users and generate frequent use of mobile money accounts. The reason cited for increased mobile money activity is the bill pay service for making PAYG solar payments. There is only one study that we found at the time this report was written that established increased mobile money activity beyond bill pay in accounts of PAYG users after adoption of the PAYG system. This research was conducted in Ghana by CGAP in partnership with the solar company PEG Africa and the mobile money service provider Tigo Cash. According to the results of the study, average PEG users checked their balances and cashed in and out more frequently and made over three times more person-to-person transfers per user than non-PAYG users. An important caveat underlined by the study is that only 16 percent of PEG users were active mobile money users.

Given the lack of robust evidence to substantiate the hypothesis that PAYG solar devices are driving digital financial inclusion, we delved deeper into this question in this research.

5 Formal banking services such as deposits that let you earn interest alongside building savings and access to loans at reasonable interest rates that can aid in expanding businesses, make a true impact in decreasing poverty.

3 METHODOLOGY

In this section, we provide an overview of the research methods used, the sample size and geographical scope.

RESEARCH METHODS

This mixed-methods study applies a combination of telephone customer surveys, comprising an initial survey (n=554) and a follow-up survey (n=498)[6] with the same set of respondents as the initial survey, conducted in two regions of Uganda between 2015 and 2017. This is further supplemented with in-person customer field interviews (n=105) held with a subset of respondents to the phone surveys. In addition, the study analyses data on mobile money transactions obtained from MTN Uganda for the customer sample (n=458) (see Section 5). Moreover, the research draws on field observations about market conditions, and interviews conducted with retailers.[7] To fill in key details that influence adoption, we also mapped the locations of retail shops and collected other delivery chain details in the districts selected for the study (Section 4).

Energy adoption patterns were documented primarily using phone and in-person surveys of end-users of solar products. It was important to observe the behaviour of users at varying levels of solar product adoption to understand how users adopt off-grid solar technologies and to test whether buying small solar products led to subsequent purchases of larger systems. To achieve the sample, respondents were recruited from the sales databases of SunnyMoney, Greenlight Planet, Fenix International and SolarNow. Customer data obtained through these partner organizations enabled us to select a random sample of respondents in the regions where the study was implemented. In each case, the selected respondents had bought at least one solar product in 2015. We grouped the customers into three groups (or levels) based on the size of the system they had adopted (see Figure 2).

- **Level 1** of solar energy access involved solar lamps (or SPLs, as they have been referred to in some of the published reports on off-grid solar energy products), with solar modules ranging from 0.3W to 3W, with large solar lamps capable of charging mobile phones. The products included in the study were purchased through the distribution channels of SunnyMoney and Greenlight Planet. These companies are among the largest distributors of solar lamps in Uganda that have met the standards established by the Lighting Global programme (Lighting Global, 2018b). Most of these products were purchased by customers on a cash basis, although some were sold on credit.
- **Level 2** of solar energy access involved mini-SHS products, with solar modules ranging

6 The reduced sample size is due to respondent attrition between the initial and follow-up surveys. More details on attrition can be found in the following subsection 'Sample size'.

7 The methods for the study were reviewed and approved through the Institutional Review Board for the Protection of Human Subjects of Humboldt State University (approval code: IRB 15-017).

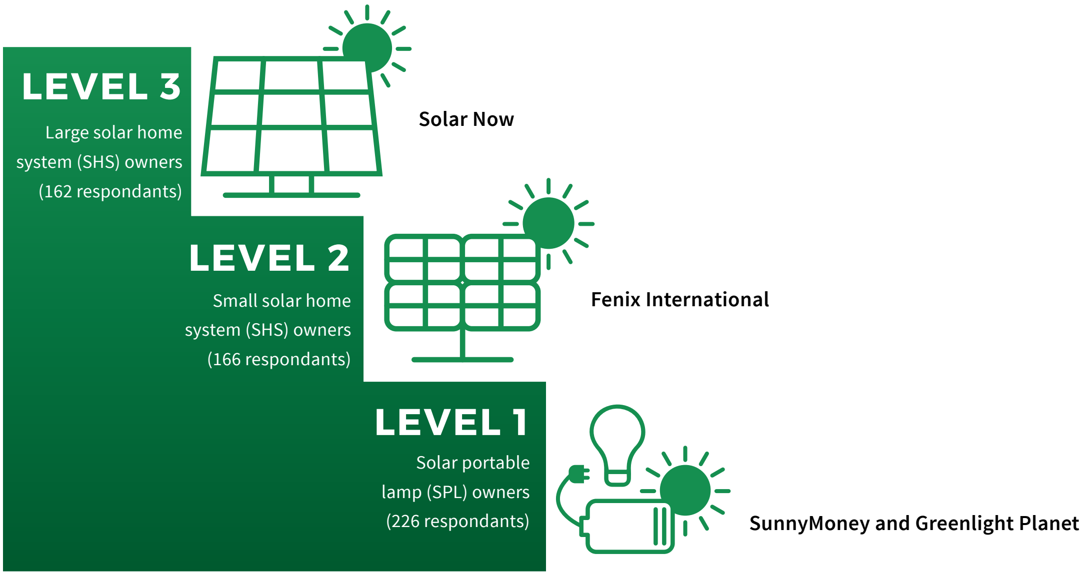

Figure 2. Subjects were existing users of solar technologies of varying size and end-uses and were recruited from four solar organizations

from 10W to 34W. Depending on the system size, these products included three or four LED light points, a radio, ports for charging mobile devices, and a TV. The partner organization for this segment of the study was Fenix International, which is a leading seller of mobile-money-based PAYG systems[8] in Uganda. All study participants in this group purchased a system in 2015 using a PAYG arrangement.

- **Level 3** of solar energy access involved SHSs that included a solar module of 50W or more. The systems could power multiple lights plus appliances such as TVs, radios, mobile phones and others. The respondents in our study had purchased the system in 2015, and some customers subsequently bought another solar PV system or additional components such as solar modules or batteries to expand the size of their existing system and/or direct current (DC) appliances that were compatible with the system. All customers from this group in our study had purchased their system using a micro-credit loan.

Grouping respondents by their level of access to solar energy allowed us to investigate differences in buyer behaviour and observe factors that influenced adoption patterns across these categories. To build the solar product adoption history, the purchases of participating households were tracked from the point the households acquired their first solar product until early 2017 (note that a few households had purchased a solar product prior to 2015, and these earlier purchases were included in the analysis). We conducted an initial survey in May–June 2016 and used this survey to build a portfolio of lighting and energy technologies and fuels used by households. The surveys catalogued solar product purchases from the respective partner organizations mentioned above, as well as purchases from other vendors. Information collected included product details, the year of purchase, financing methods and other information related to the product purchases. Most of this information was collected using telephone surveys that typically lasted 30–45 minutes. In addition, a subset of the respondents was interviewed in person to collect additional information. Using the self-reported solar product purchase histories and product use information, along with supporting details from the partner organizations (e.g. product specifications and

8 These respondents made their payments for solar systems exclusively via MTN Uganda mobile money accounts.

pricing), we built a comprehensive database of solar technology adoption over time for each participating household. A second round of telephone surveys was conducted in February 2017 to ask about the rate of subsequent solar product adoption by each respondent. See Table 1 for information about the final sample size used for analysis of the respective adoption groups.

SAMPLE SIZE

In our original sample design strategy, we created a sampling frame which would be enough to survey at least 700 respondents across the three levels of access to solar energy. Since we planned to sample respondents from the customer databases of four different organizations that had substantial differences in the number of customers, customer profiles and levels of contact details captured for customers, we expected different attrition rates across the three levels of access to solar energy. For the first round of surveys, our aim was to survey at least 80–85 percent of the 700 respondents planned in the original sampling design. Between the first and second rounds of surveys, we expected a lower attrition rate, as we would have verified, reliable contact details for the respondents during the first round of the survey.[9] We kept a higher attrition buffer in the original sampling frame for Level 1 respondents than for Levels 2 and 3. We did so because sales records that included contact details for Level 1 customers appeared to be less accurate and because we anticipated greater levels of customer service dissatisfaction within this group. Cash sales models on which SunnyMoney and Greenlight Planet sales were primarily based offer a less engaged relationship with end-users. This in turn leads to the collection of fewer customer details. In contrast, PAYG and other credit-based sales require regular interaction with customers, highlighting a greater need to maintain accurate customer databases. We were able to survey 600 respondents in the first round of surveys—an attrition rate of ~15 percent from our original sample design. We surveyed 554 of the initial 600 respondents during the second round of surveys, which corresponds to attrition of ~8 percent (see Table 1).

Table 1. Summary of the final number of surveys selected for analysis

DATA PARTNER	LARGEST PRODUCT RESPONDENTS OWNED AT THE TIME OF INITIAL SURVEY	LEVEL OF SOLAR ENERGY ACCESS AT THE TIME OF INITIAL SURVEY	PAYMENT METHOD	INITIAL SURVEY: PHONE INTERVIEWS	INITIAL SURVEY: FACE-TO-FACE INTERVIEWS*	SECOND ROUND OF SURVEY: PHONE INTERVIEWS
Sunny Money and Grennlight Planet	Entry-level single-light systems	Level 1	Cash or credit	226	52	200
Fenix International	Plug-and-play small solar home system kits	Level 2	Mobile-money-based PAYG	166	30	148
SolarNow	Advanced solar systems with larger PV panels (>=50Wp)	Level 3	Micro-credit	162	23	150
			Total respondents	**554**	**105**	**498**

Note: Respondents within the SunnyMoney/Greenlight Planet group who had a system with more than one light and the respondents within the Fenix International group that had a product with a panel size >=50W were removed. This was done to achieve three respondent groups as described in the table.

9 When one is trying to reach respondents for the first time from a given customer list, most of the attrition is likely to occur due to unreliable contact details. Between the first and second rounds of surveys, most of the attrition is likely to occur on account of respondents moving to a different location or changing phone numbers.

GEOGRAPHICAL SCOPE

To implement the household surveys, we wanted to select two districts that would represent two important off-grid solar energy trends in rural Uganda. We selected Luwero in south central and Pallisa in eastern Uganda based on the following rationale:

- We wanted the two districts to be distinct from each other in terms of socio-economic indicators, infrastructure and the presence of off-grid energy industry players and other stakeholders. We picked one district from central or western rural Uganda and one from northern or eastern Uganda. This approach was supported by the feedback we received in the Energy Ladder Research Workshop held on 22 March 2016 in Kampala, where participants confirmed that south and central Uganda had relatively better infrastructure and higher per capita income than northern and eastern Uganda.
- We made the final selection of districts based on sales data from partners for 2015. We sought to select districts that had relatively high sales for all of our partners. SunnyMoney sales were higher in Luwero than in any other district in Uganda in 2015, and the sales numbers for Fenix International and SolarNow were the fourth highest in Luwero that year. In the east, we selected Pallisa because sales by both Fenix and SunnyMoney were relatively high, and it was further geographically from Luwero than other districts with high sales in eastern Uganda. It should be noted that SolarNow did not sell products in Pallisa in 2015.[10]

Based on our field observations, Luwero appeared to be a relatively well-off district with a reasonably high level of economic activity that was spread across markets in several towns. In contrast, in Pallisa the economic activity appeared to be more limited and was concentrated in the main town. In Luwero, we observed more economic activity on the streets (e.g. a large number of banana sellers). Also, the district headquarters offices were more organized and busier. We also witnessed a greater number of businesses and bank branches along the highway in Luwero than in Pallisa. During our initial visit to Pallisa, there had been no electricity for four continuous days as of 1 April 2016, the day we arrived for our visit. We were in Pallisa for three days on that visit, during which there was power for two or three hours per day, with large voltage fluctuations. Pallisa appeared poorer in comparison, and this was corroborated by the feedback we received during the stakeholder workshop on 22 October and in conversations with the sales staff of our partner organizations stationed in Pallisa. Both districts had largely agrarian populations, with fishing another leading occupation, as both districts had access to freshwater lakes.

10 We did not base the selection of a district in the eastern region on SolarNow sales, since its sales in any single district in the east were not sufficient to cover the SolarNow respondent cohort. Instead, we surveyed SolarNow customers from districts adjacent to Pallisa, including Kumi and Soroti.

4

SOLAR PRODUCT RETAILER SURVEYS AND RETAIL FOOTPRINT MAPS

In each district, we carried out a mapping exercise to identify the locations of retail outlets for solar product sales and to collect other data related to the solar product supply chain[11] in mid-2016.

PALLISA DISTRICT

In Pallisa district, most economic activity is concentrated in Pallisa town, its municipal, administrative and commercial centre, instead of being spread out in the markets of several towns, as was the case in Luwero. There are a handful of electronics shops in Pallisa town, only four of which stocked solar components such as solar PV panels, direct current (DC) to alternating current (AC) inverters, batteries and charge controllers. Two supermarkets in Pallisa town stocked generic, low-quality solar torches, and one of them also stocked solar PV panels. Apart from this, some stalls in the weekly evening market in Pallisa also sold small (5–10W) PV panels and generic, low-quality solar torches.

Although we did not find shops that sold large PV panels and large, assembled solar kits in Pallisa, there was a substantial presence of quality-assured off-grid solar products via exclusive solar showrooms or agents. Fenix's business model relies on leveraging the distribution network of MTN Uganda. It set up a desk inside the MTN main office or shop in the districts where they are present. In Pallisa town, it operates from the MTN shop there. SolarNow used to have a branch in Pallisa; however, it shifted this branch to Kumi, the neighbouring district, due to sales challenges in Pallisa. It continues to market its products in Pallisa through the Kumi branch. Pallisa is a poor district, and this is reflected in the sizes of the systems that are available there. SolarNow systems are large, with the base system starting with a 50W panel.

SunnyMoney had one agent in Pallisa, a staff member at one of the local Savings and Credit Cooperative Organizations (SACCO). His position at the SACCO works greatly in SunnyMoney's favour, as he markets these products to members of his SACCO and to members of the neighbouring farmers' association. However, due to an unreliable supply of products, the agent is unable to realize his full sales potential. Greenlight Planet markets its products through the teachers' SACCO. While the SACCO drives high sales, it faces working-capital constraints. The Greenlight Planet distributor from which the SACCO gets its supplies does not accept postdated cheques. Since the SACCO receives its customer payments at the end of each month, when the teachers receive their salaries, the SACCO is not able to expand its stock and realize its full sales potential.

Village Energy has a substantial presence in Pallisa, with six branches in the district. Its main branch is in Pallisa town, and it has five other branches in the towns of Gogonyo, Kasodo, Agule, Kameki and Kamuge (see Figure 3). All the branches stock Greenlight Planet, d.light

11 This was based on a full review of the solar product market, including active players other than SunnyMoney, GreenLight Planet, Fenix International and SolarNow.

Figure 3. Geographical distribution of shops and branch offices that stock and sell solar products in Pallisa district

Note: VL = Village Energy

and JUA Energy products in additional to solar components, and all are capable of performing repairs and installation. Village Energy was the only example we found in our survey of the two districts in which an organization's branches had penetrated deep into the district, rather than being located on the highway or in the market of the main town.

Figure 3 shows the geographical distribution of the shops and branch offices that stock and sell solar products in Pallisa district. It is notable that the six Village Energy branches (shops) are spread out in various towns in the district, while the other shops congregate in the main town of Pallisa.

LUWERO DISTRICT

The Gulu–Kampala highway runs through Luwero district, and electronics shops along the highway sell solar components such as solar panels, inverters and batteries. Depending on the size of the shops, they also stock DC appliances and assembled solar system kits that may or may not be quality-assured through Lighting Global. The first two images in Figure 4 show examples of such shops. In some cases, they would also stock entry-level quality-assured products such as those of d.light and Greenlight Planet. This was often the case when a shop staff member or owner was a SunnyMoney agent. While the electronics shops could be found both in the markets of towns and along the highway, the exclusive solar showrooms such as those of SolarNow, Fenix International, M-Kopa Solar, Kirchner Solar and Solar Solutions were found only along the highway. The staff in these shops felt that such a central position for the shop was a good strategy, as it allowed the sales staff to reach out to the villages located along or near the highway. SoLight was also present, although its shop was located in a market away from the main highway. To understand the distribution network of off-grid solar products in Luwero, we visited several electronics shops and interviewed their staff. Areas covered included the section of the Gulu–Kampala highway that runs through Luwero district, Luwero town—the municipal, administrative and commercial centre of Luwero district—and another nearby town called Wobulenzi. The red dots in Image 5 in Figure 4 represent the shops whose staff we interviewed.

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2
3
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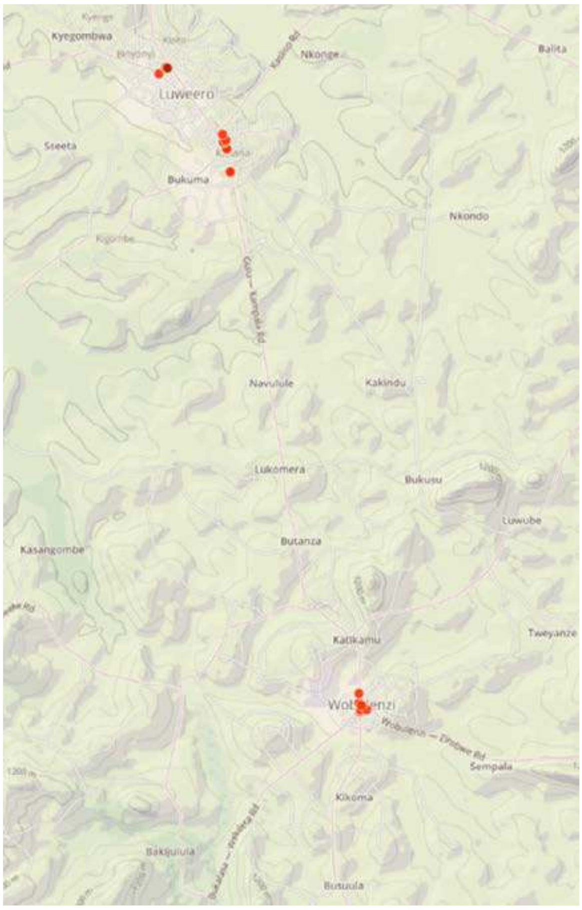


Figure 4. Retail shops in Luwero district

Image 1: Example of electronics shop stocking solar components ; Image 2: Example of electronics shop stocking solar components ; Image 3: Solar Solutions shop; Image 4: M-Kopa Solar shop; Image 5: Solar shops interviewed in Luwero district

Note: Images 1–4 are examples of shops that stock solar components in Luwero district; Image 5 shows the approximate locations of the shops whose staff we interviewed in Luwero district.

KEY INSIGHTS FROM THE SOLAR PRODUCT DISTRIBUTION MAPPING EXERCISE

- **Linkages between per capita income, electricity outages and adoption of off-grid solar technology:** We witnessed strong demand for and awareness of off-grid solar products in both Luwero and Pallisa. In Pallisa, as the duration and frequency of power cuts is more pronounced, the use of solar technology becomes more attractive. It is common to see SHS kits or other assembled systems installed in commercial establishments in Pallisa town. While it is relatively easier to convince a prospective customer of the value of investing in such systems, limited income and a lack of access to a meaningful range of solar products represent greater constraints to adoption. As a result, small and affordable solar products—rather than larger systems—are commonly adopted. Additional constraints include availability of solar products (as noted above regarding issues faced by the SunnyMoney agent) and working capital (which we witnessed regarding the ability of the Palissa Teachers' Association to stock sufficient Greenlight Planet products to meet demand). The use of off-grid solar energy in Pallisa becomes especially attractive when compared with grid-based electricity for two reasons:

» **Perception of grid electricity as dangerous:** The quality of power—when it is there—is poor, and so is the servicing of the electricity poles. We noticed many 'dancing' (or leaning) electricity poles stationed in rice paddy fields (see Figure 5 for an example of a pole under high tension that had collapsed); farmers continued to work in their fields despite the danger of electric shock. According to an incident narrated to us by the SACCO staff in Pallisa, eight people had died in an electricity-related accident during a wedding ceremony. It should be noted that in this instance grid electricity was being tapped illegally, which is a dangerous practice.

» **Grid electricity is expensive:** This is true for the whole of Uganda. The cost of electricity for domestic consumers is especially high, as they subsidize industrial consumers for shoulder and off-peak loads. Further, the cost of electricity in Uganda increased consistently in each quarter of 2015 and further in the first quarter of 2016, which was when we visited the region. According to the power tariff schedule published by the Ugandan Electricity Regulatory Authority for tariffs in effect on 1 January 2016, the power tariff for domestic consumers was about US$0.20 per kWh consumed above the first 15kWh.

- **Linkage between product quality and financing of off-grid products:** One reason for the absence of low-quality or generic solar products in Pallisa, especially for larger systems, can be attributed to low per capita income in the district. All solar systems bigger than entry-level lighting products were bought using some form of flexible financing. People in Pallisa typically do not buy off-grid solar products with complete upfront payments, except in the case of small, entry-level products. In Fenix's case, PAYG financing is used. For many other products, SACCOs provide financing for credit-based sales. As energy lending is likely to occur only in the case of quality products, and villagers are unable to afford bigger systems without this, this potentially contributes to the low presence of component-based solar systems and generic solar products.

Figure 5. Collapsed electricity pole on farmland along the Kampala–Tirinyi highway that crosses Pallisa district

Figure 6. Fenix staff conducting customer outreach activites

From top: Branded vehicle used by Fenix staff to reach deep into villages; Fenix staff during customer outreach activities in a village in Luwero district

- **Sales trends are tied to farming seasons:** Both Luwero and Pallisa are largely agrarian societies, and the sales staff of solar shops we interviewed confirmed that the period between February and May is a low sales period, as it is the crop-planting season. Sales pick up in June, when crop harvesting begins, and strong sales continue until January of the next year, with a continued spike during the holiday (Christmas) season in December–January.
- **Peer effect and referral sales:** There are substantial peer effects and positive demonstration effects associated with sales of off-grid energy products, particularly if the product performs reliably. A satisfied customer is likely to buy another product for his or her relative or recommend it to a friend or neighbour.
- **Comparison of different sales strategies:** Village Energy was the only example we found in the two districts of a company that had branches deep in the district, rather than being located on the highway or in the market of the main town. Other exclusive solar retailers (with the exception of Fenix agents that sell from MTN stores) typically set up a single showroom in the main town or on the district highway and invest substantially in agents that reach out deep into the villages. Fenix provides its staff with branded four-wheel-drive cars so that they can travel deep into the districts for client outreach. Fenix also recruits enterprising young staff, many of them young university students or recent graduates (see the images in Figure 6). It is unclear whether any of these sales strategies have a competitive edge over another.
- **Benefits and costs associated with interventions that are not sustained over time:** Through the work of the SunnyMoney agent in Pallisa, the people of Pallisa have been highly sensitized to the benefits of solar energy. SunnyMoney's interventions helped create high demand for solar products, and many of the people who bought entry-

level products now want to buy bigger systems.[12] However, there are issues with a sales model that is not sustained over time that can suppress sales and hamper market development. According to the SunnyMoney agent in Pallisa, the supply of these products has been sporadic since the SunnyMoney school campaign ended. He may or may not receive a supply from SunnyMoney during any given quarter, and he typically must go to Kampala to purchase solar products to restock. Further, SunnyMoney customers in Pallisa are unable to receive adequate aftersales service support. Once the sales campaign ends, it is difficult for customers to access repair services from the manufacturer under warranty claims, as access to SunnyMoney staff diminishes.

OUR ANALYSIS OF THE SITUATION

- Strong awareness campaigns lead to increased sales; however, there could be negative impacts if energy providers then fail to supply products consistently after the campaigns end or do not provide sound aftersales services. We are concerned that such an approach can lead to customer frustration and disillusionment. For most of these customers, the products they purchased during the SunnyMoney campaign were their first solar products. This experience may, therefore, influence their perception of off-grid solar technology for a long time.
- Many of the technical issues that arise in products can be addressed if the agents receive basic training in managing solar product inventory and customers are given basic instructions on how to manage their products to optimize performance and increase their lifespan. If certain basic instructions—such as: (a) products with lead acid batteries should be charged periodically even when not in use; (b) wires should not be coiled tightly; and (c) the solar panel should be positioned to ensure good exposure to the sun—are given to the agents and customers, then some of the technical issues related to battery life, damaged wires and daily operation time are likely to be reduced.

12 A lack of options for purchasing solar products is indicative of the greenfield character of the off-grid solar products market in Uganda. We talk about this more in ‘Key prior experiences or information that influenced users to purchase each of the solar products they own’ in Section 5.

5 ANALYSIS AND RESULTS

This section presents analysis and insights related to solar product adoption patterns, customer preferences for the adoption of subsequent products, and the potential impact that digital solar payments have on digital financial inclusion.

ADOPTION PATTERNS OF OFF-GRID SOLAR ENERGY TECHNOLOGIES AND FACTORS THAT INFLUENCE ADOPTION

To quantify trajectories of households' access to solar energy over time, we used data from the surveys, product sales data from the partner organizations and product specifications to estimate the level of off-grid solar energy service received by each household. Energy service was estimated in units of watt-hours (Wh) of available electricity per day for each calendar year. The results of these calculations are presented in Figure 7. Each thin line in the figure represents the trajectory of the level of energy service for a single household in an access-level category (i.e. Level 1: households that adopted a solar lamp in 2015; Level 2: households that adopted a mini-SHS in 2015; and Level 3: households that adopted a larger SHS in 2015). The thicker lines

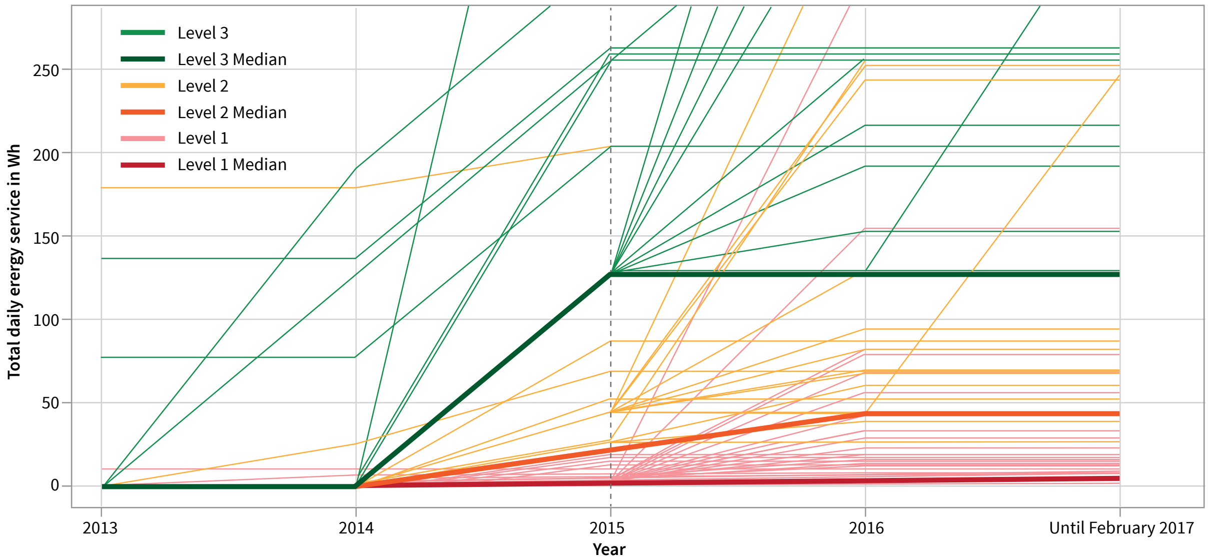


Figure 7. Energy service level trajectories for individual households in units of watt-hours per day (Wh/day) of electricity

Note: The data are presented by access level group according to purchases made in 2015, where Level 1 users purchased a solar lamp with a 0.7–3W solar module in that year, Level 2 users purchased a mini-SHS kit with a 10–34W solar module, and Level 3 users purchased a larger SHS with a solar module >= 50W. The graph shows energy service levels up to 250Wh/day to focus attention on the adoption trends characteristic of most end-users. As a result, some outlier households with higher levels of energy service are not shown (e.g. some 'Level 3' respondents had daily energy service values exceeding 600Wh). The thicker lines indicate median values for each category. Note that a few households in the study had adopted products prior to 2015, and this is indicated in the figure. See Annex 1 for supporting data on assumptions used to calculate daily energy service levels.

indicate the median trajectory for the respective access-level categories.

Figure 7 indicates that the level of service for SPL users (Level 1) was the lowest in 2015, with a median level of about 2Wh/day, followed by mini-SHS users (~40Wh/day) and large SHS users (~130Wh/day). Moreover, energy service levels for most customers who purchased a solar lamp in 2015 remained low through early 2017, although the median service level did increase to about 4Wh/day based primarily on purchases of additional solar lamps. The median service level for those who purchased a mini-SHS or large SHS in 2015 remained relatively constant through February 2017. These results indicate that some households that bought solar lamps purchased additional small-scale energy products to build their energy service portfolio over time, but their overall service levels remained considerably lower than those of households that bought mini-SHSs and SHSs. In contrast, the primary trend for households that bought mini-SHS kits or large SHSs was relatively static after their 2015 purchase, as many households did not purchase additional solar products or systems following the 2015 purchase through February 2017 (though they were making periodic payments towards the purchase of their systems during this period). For more details, see Annex 1.

IS ADOPTION DRIVEN IN LINE WITH THE SOLAR ENERGY LADDER HYPOTHESIS?

The criterion used for the sampling of respondents in this study was that a prospective respondent should have bought at least one solar product in 2015. More than 97 percent of respondents bought their first solar product in 2015, regardless of system size. Figure 7 shows a sudden increase in levels of daily energy service in 2015. Since 95 percent or more Level 2 and Level 3 respondents had purchased their SHS as their first purchase of a solar product (i.e. they did not purchase an SPL prior to purchasing an SHS), the solar energy ladder hypothesis does not hold for this study's respondent base (see Table 2).

Table 2. Percentage of respondents who purchased a solar product for the first time in 2015

	RESPONDENTS WHO BOUGHT THEIR FIRST PRODUCT IN 2015	TOTAL RESPONDENTS	%
Level 1	221	226	98%
Level 2	163	166	98%
Level 3	150	162	93%

MOTIVATIONS FOR END-USERS

Level 2 and 3 users were asked to report factors that made them comfortable investing in an SHS as their first solar product purchase. As shown in Figure 8, they were motivated predominantly by a demand for multiple light points and attractive product-bundling options. Flexible payment terms and affordability were also very important for Level 2 users.

A substantial majority of Level 2 and Level 3 respondents purchase a multi-light SHS because they need more than one light, due to a large family or a house with multiple rooms. For both Level 2 and Level 3 users, an attractive product bundle is the second most important motivating factor. Advanced solar systems at Level 3 allow a high degree of customization; systems as large as 250Wp or more can be built, and various DC appliances or components such as an inverter to charge AC appliances can be added, depending on users' needs. Flexible payment terms and affordability are greater incentives for Level 2 users than for Level 3 users.

The income levels of Level 1 and Level 2 respondents are similar, but those of Level 3 users are substantially different (see Figure 9, and Annex 1 for instructions on how to interpret a boxplot). Welch's ANOVA test for unequal variances shows that incomes are significantly different between the three levels. Further, the Tukey multiple pairwise comparison shows that the difference in the mean income of Level 1 and Level 2 households is statistically insignificant, while the differences in mean income between Level 1 and Level 3 households and between Level 2 and Level 3 households are statistically

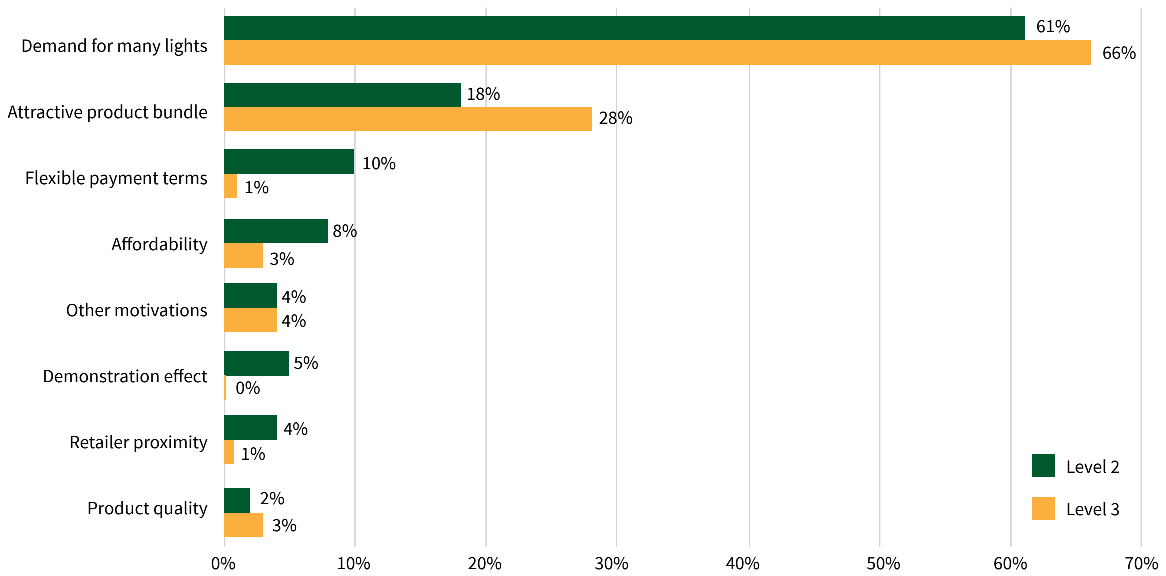


Figure 8. Reasons why Level 2 and Level 3 respondents bought an SHS as their first solar product purchase

Note: The graph reports percentages within each level. For example, 66 percent of Level 3 respondents bought a big system due to a demand for many lights. Each respondent could report more than one motivation.

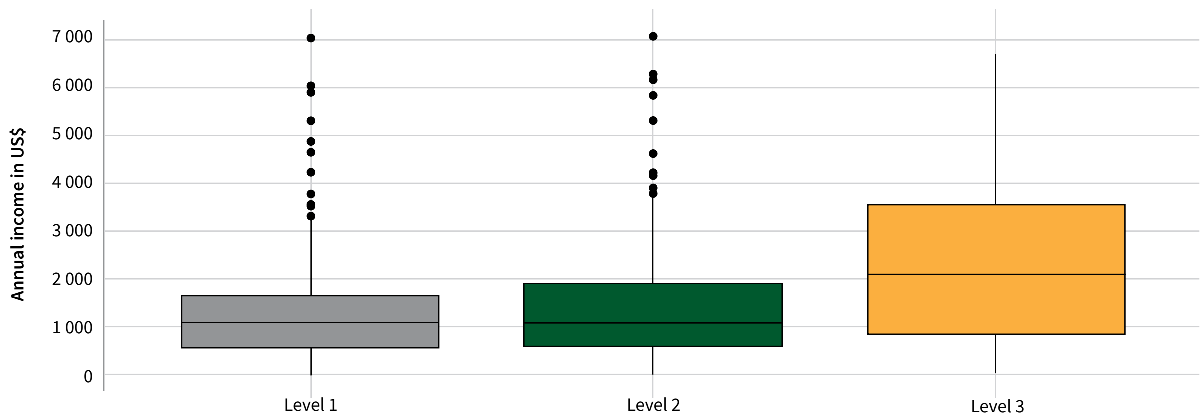


Figure 9. Annual income levels of respondents

Note: The black line in the middle of each coloured rectangle indicates the median annual income for that level. The graph has been zoomed to optimize the graphing area. Some outliers have been excluded. The biggest outlier goes as high as $31,224.

Table 3. Test results for Welch's one-way ANOVA and Tukey multiple comparisons of mean incomes for the three levels of solar product adoption

Welch's one-way analysis of means (not assuming equal variances)
Data: Annual_income_USD and Solar_level
F = 10.045, num df = 2.00, denom df = 220.38, p-value = 6.685e-05

Tukey multiple comparisons of means at 95 percent family-wise confidence level
Data: Annual_income_USD and Solar_level

PAIR	DIFFERENCE BETWEEN MEANS	LOWER END OF CONFIDENCE INTERVAL	UPPER END OF CONFIDENCE INTERVAL	ADJUSTED P VALUE
Level 2-Level 1	316.6003	-446.8404	1080.041	0.5929354
Level 3-Level 1	1484.0460	743.0381	2225.054	0.0000099
Level 3-Level 2	1167.4457	347.4542	1987.437	0.0025386

significant (see Table 3 for the results of Welch's ANOVA test and the Tukey multiple pairwise comparison test). Since Level 3 systems are substantially larger, at 50Wp or more in solar panel size, it is not surprising that households with higher incomes are purchasing them. At the same time, Level 2 systems are much bigger (typically 10–17Wp in panel size) than the entry-level systems of Level 1 respondents (typically less than 3Wp). Given that users at these levels fall into similar income groups, flexible financing options play a greater role in increasing affordability for Level 2 users than they do for Level 3 users.

KEY EXPERIENCES OR INFORMATION THAT INFLUENCED USERS TO PURCHASE SOLAR PRODUCTS

An end-user may be exposed to several channels and types of information related to the application and benefits of solar products. These include advertisements on radio channels, market demonstrations undertaken by sales teams, seeing a solar product being used in an acquaintance's home or business establishment, or a solar product referral. End-users are not necessarily exposed to all possible information sources before their purchase decision. However, due to the increasing number of interventions related to solar-based energy, end-users are being exposed to persuasion attempts from multiple sources, leading to a 'multiple source effect'.[13] Figure 10 depicts the multiple source effects experienced by users that influenced them to make their solar product purchases. The respondents in this study helped identify a total of 758 information effects for the 628 products they collectively owned without any surveyor prompting. Direct marketing efforts by solar retail organizations reportedly influenced the purchase of over 70 percent of the products owned by the respondents at the time of the initial survey. Other factors such as word of mouth reportedly contributed to the purchase of 26 percent of products, and demonstration effects reportedly contributed to the purchase of 19 percent of products.

Interactions with retail agents are the key driver for end-user purchase and product selection

As noted in Section 4, most retailers selling solar products are located in the markets of main towns or along the highway. As the highway cuts across large sections of the respective districts, and the markets in the main towns attract a heavy footfall of villagers interested in doing commercial transactions, these central locations allow the retailers to reach large sections of the district population. The sales agents often navigate deep into the villages on both sides of the highway to market solar products. Customers who do not access the highway or are far from the main town, therefore, do not fall in close proximity to the retailers. Uganda has characteristics of a greenfield market, where households, depending on their proximity to commercial trading centres, have varying access to solar product retailers who enjoy limited competition. By 'greenfield market' we imply a market where there is relatively little competition between retail vendors, and the companies can find customers who have never talked with another vendor. Many other countries in sub-Saharan Africa are even more nascent. This provides insight into why retailers of solar products and systems have been successful in selling products to first-time solar purchasers.

13 Harkins and Petty (1981) identify and describe the multiple source effect as when "…information presented by multiple sources received greater scrutiny than did the same information presented by a single source. One implication of this was that when multiple sources presented strong arguments, the arguments elicited more favorable issue-relevant thoughts and more agreement than when the same strong information was presented by a single source."

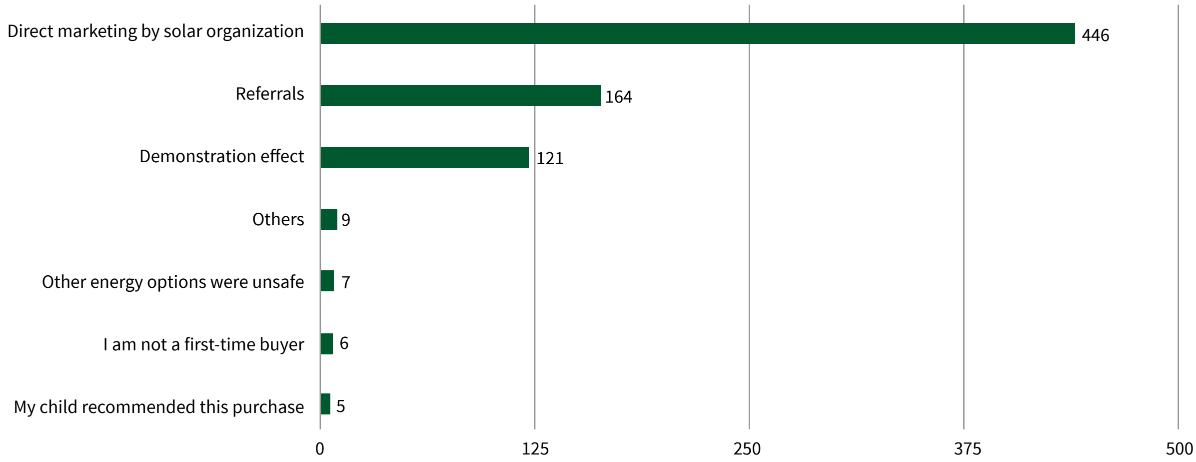


Figure 10. Summary of factors that influenced end-consumer purchasing decisions, based on survey responses to the question, "What prior experiences or information influenced you to purchase each of the solar products that you own?"

Note: Respondents could cite more than one factor.

Motivation for purchasing solar home systems is not based on financial payback but is related to improved quality of life

Many practitioners argue that the combined effect of avoided energy spending on traditional fuels after purchasing solar products and the flexible financing instruments with easy instalments help increase the affordability of solar systems (Africa Progress Panel, 2015; The Climate Group, 2015; Langat, 2017). We investigated the net benefit and cost of investing in solar systems for respondent groups at each of the three levels of solar energy access. The assumptions used in the analysis do not describe economic decisions that users may take in reality. Net present value (NPV) analysis is performed to illustrate that the purchases of large solar systems are not purely an economic investment (i.e. these investments do not pay for themselves from the avoided spending on traditional fuels). There are other motivations for the purchases, such as an improved quality of life, that more than compensate for the net cash outflow of investments in solar systems.

Net present value analysis

Respondents in this study reported making substantial savings across all levels (see Figure 11). The median user at Level 1 saved $2.60 per month, at Level 2 saved $3.70 per month, and at Level 3 saved $5.50 per month. These savings indicate avoided expenditure on status quo fuels after users switched to solar products and are not adjusted for solar energy payments. Further, SHSs at Levels 2 and 3 were financed to the consumer using PAYG and micro-credit, respectively, which is expected to increase affordability. We identified typical users of solar products within each solar energy level to perform an NPV analysis comparing the solar scenario to the scenario where the user does not use any solar products. These example cases are described as follows.

Level 1

1.1 Solar lantern user: Approximately 43 percent of Level 1 users purchased a 0.5W lantern that met Lighting Global standards in 2015, and did not purchase a solar product over the following two years.

1.2 Single solar light with mobile charging user: The median energy service derived from various solar products owned by Level 1 users closely corresponds to the use of a 1.5W solar lantern with mobile charging. This product meets the Lighting Global quality standards. The users purchased the light in 2015 and did not buy any other solar product over the following two years.

Level 2

2.1 Small four-light kit user: Approximately 35 percent of Level 2 users purchased a 17W

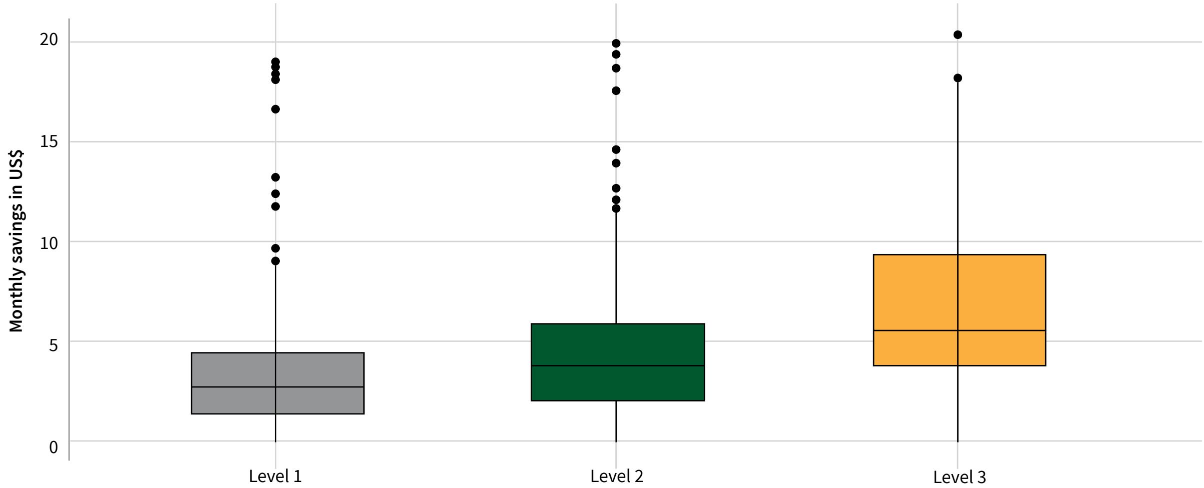


Figure 11. Monthly savings in US$ in energy spending on status quo fuels across three levels of solar energy access

Note: The black line in the middle of each coloured rectangle indicates the median monthly savings for that level. Monthly savings are aggregate savings from reduced consumption of kerosene, candles, dry cells and instances of paid phone charging.

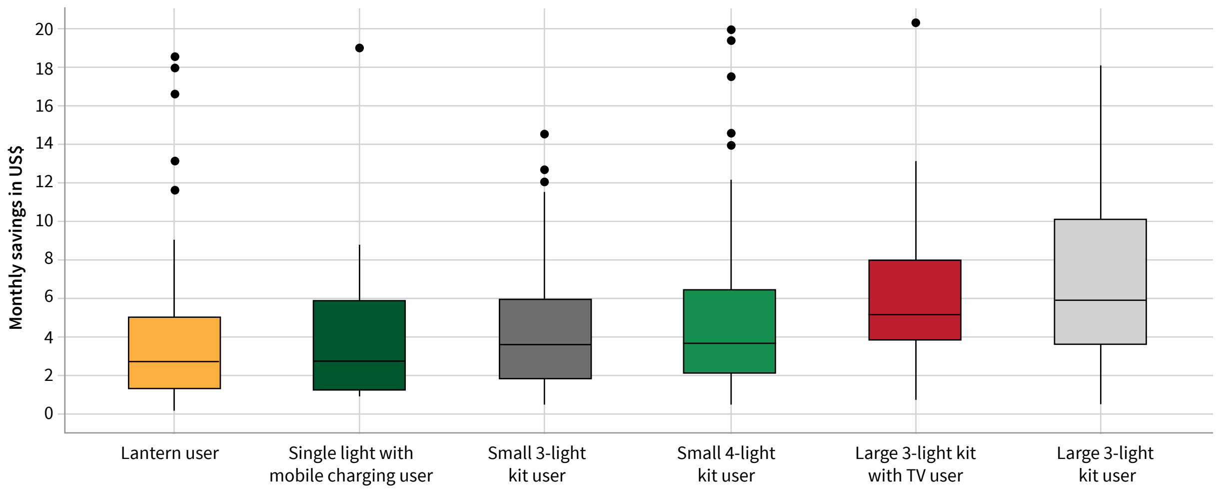


Figure 12. Monthly savings for typical customers of each level of solar energy access

Note: The black line in the middle of each coloured rectangle indicates the median monthly savings for that level. The graph has been zoomed to optimize the graphing area. Some outliers have been excluded. Some outlier respondents reported monthly savings going up to $50.

product with four lights, mobile charging and a radio with a built-in torch. They purchased the product in 2015 and did not purchase any other solar product over the following two years.

2.2 Small three-light kit user: Approximately 22 percent of Level 2 users purchased a 10W product with three lights, mobile charging and a radio with a built-in torch. They purchased the product in 2015 and did not purchase any other solar product over the following two years.

Level 3

3.1 Large three-light kit user: Approximately 37 percent of Level 3 users purchased a 50W product with three lights, mobile charging and a radio.

3.2 Large three-light kit with TV user: Approximately 34 percent of Level 3 users purchased a 50W product with three lights, mobile charging, a radio and an 18.5-inch TV.

See Figure 12 for a comparison of savings for these typical customers in association with the use of their solar product or system and associated reductions in the cost of conventional energy sources such as kerosene fuel or mobile phone charging.

An NPV analysis was performed assuming the solar product was purchased in January 2015. The objective of this analysis is to understand the net benefit over a two-year period instead of doing a life-cycle analysis. We selected a two-year period for this analysis because the warranty periods across branded off-grid solar products owned by respondents typically range between one and two years. Further, the repayment periods for the mini-SHSs (Level 2) and SHSs (Level 3) were one and a half years and two years, respectively. Field observations indicate that the life cycles of off-grid solar products vary over a broad range. It is, therefore, difficult to identify a common life-cycle period across the range of solar products owned by respondents across the three levels. The two-year period selected, corresponding to the upper limit of the warranty and repayment periods, provided a common period for the analysis.

For the NPV analysis we considered median savings in energy spending on traditional fuels and mobile charging investment in solar products in accordance with the payment plan for the product. Forgone interest earnings for users with net cash outflow during the first two years of purchasing a solar product that would have accrued had the users saved money in a commercial bank savings account instead of spending on a solar product have been factored into the analysis. Similarly, for users who had a net cash inflow during the first two years of purchasing a solar product, interest earnings of cash inflow have been factored in. The interest earnings in both cases have been adjusted for withholding tax on interest payments. Cash outflows have been discounted using the average annual end-of-year headline inflation values in Uganda for 2015 and 2016 to obtain the NPV in January 2015 money. Given that users bought systems of varied sizes, a normalized metric—NPV per unit of energy service measured in KWh ($/KWh)—was computed. It is derived using the following equation:

$$\text{NPV per unit of energy service} = \frac{\text{NPV over 2015 and 2016}}{\text{Sum of energy service available in years 2015 and 2016}}$$

For solar lanterns and single-light systems, the NPV is positive; users break even within the first year of product ownership. For lantern users, the NPV is ~$57, with a breakeven period of four months. For customers using single-light solar products with mobile charging, the NPV is ~$41, with a breakeven period of 10 months. For all typical SHS users, the NPV is negative, ranging between minus $100 and minus $735 depending on the size of the system (10–50Wp in solar panel size). Moreover, the breakeven period exceeds the warranty period offered on the system in all mini-SHS and SHS cases by a substantial margin. Investment in an SHS is, therefore, not paid for by savings in spending on traditional fuels. Instead, there is substantial net cash outflow after purchasing a system. The financial business case of investing in an SHS is strengthened only if the purchase of the system enables new income to be generated from economically productive activities.

Given the substantial net cash outflow from investing in big systems, it would appear that flexible payment mechanisms that allow payment over time help break the affordability barrier. However, since the NPV loss increases by 35–40 percent for Level 3 users by opting for the flexible financing option, as opposed to paying for the full cost of the system upfront, the high cost of solar products is felt even more (see Table 4 for detailed results and Annex 2 for assumptions used in the analysis).

Apart from users who invest in Level 2 or Level 3 systems for direct income-generating activities, the motive for purchasing these systems for home use does not appear to be based on financial payback. The benefits related to an improved quality of life far outweigh the financial incentives. Furthermore, there are also incentives related to low turnaround times for repair or product replacement in case of technical issues with products. Retailers of larger systems invest substantially in aftersales service. Retailers are more accessible by way of customer care numbers and store footprint. As discussed in Section 4, in Uganda, entry-level systems are often sold by a network of agents, and not directly by retailers or distributors. The second popular method of selling entry-level lights is through school campaigns conducted by SunnyMoney, which typically last four months. At the end of the school campaign, SunnyMoney shifts its focus to

Table 4. NPV and breakeven periods for typical customers of each level of solar energy access

CUSTOMER TYPE	LEVEL OF SOLAR ENERGY ACCESS	SOLAR SCENARIO DESCRIPTION		NPV OVER TWO YEARS FROM PURCHASE IN 2015 MONEY	$/KWH OF NET BENEFIT OR NET COST*	BREAK-EVEN PERIOD IF LESS THAN 2 YEARS	COMMENTS
		PAYMENT METHOD FOR SOLAR PRODUCT	LEVEL OF MEDIAN MONTHLY SAVINGS IN SPENDING ON STATUS QUO ENERGY FUELS				
Lantern user	Level 1	Complete upfront payment of $10	$2.76	$56.84	81.1	4 months	Almost 5.7x benefit
Single light with mobile charging user		Complete upfront payment of $24.2	$2.76	$40.62	16.1	10 months	Almost 1.6x benefit
Small 4-light kit user	Level 2	Complete upfront payment of ~$206	$3.71	$(160.68)	(5.4)	NA	There is a substantial net cash outflow in shifting to a Fenix Home Comfort Kit in the first two years. If the system leads to sufficient new economic activity equivalent to the NPV loss in two years, there is an economic case for purchasing the product.
Small 3-light kit user		PAYG payment plan: Down payment: $25.5; Monthly payment: ~$12.2; Repayment period: 18 months”	$3.71	$(179.12)	(6.0)	NA	
		Complete upfront payment of ~$156	$3.61	$(102.16)	(3.7)	NA	There is a net cash outflow in shifting to a Fenix Home Plus Kit in the first two years. The business case of investing in the system will be strengthened if new income is generated by economic activity in the household due to the system.
		PAYG payment plan: Down payment: $18; Monthly payment: ~$10; Repayment period: 18 months	$3.61	$(127.85)	(4.6)	NA	
Large 3-light kit user	Level 3	Complete upfront payment of ~$375	$6.00	$(312.18)	(6.5)	NA	There is a substantial net cash outflow in shifting to SolarNow solutions in the first two years. If the system leads to sufficient new economic activity equivalent to the NPV loss in two years, there is an economic case for purchasing the product.
		PAYG payment plan: Down payment: $72; Monthly payment: $19.50; Repayment period: 24 months	$6.00	$(433.23)	(9.1)	NA	
Large 3-light kit with TV user		Complete upfront payment of ~$546	$5.25	$(541.43)	(4.0)	NA	
		PAYG payment plan: Down payment: ~$117; Monthly payment: ~$28.50; Repayment period: 24 months	$5.25	$(735.39)	(5.4)	NA	

*Note: * $/KWh refers to the NPV per unit of energy service (measured in KWh) that is available to the users in the first two years of product ownership. It is derived as NPV divided by the sum of the energy service available in 2015 and 2016.*

running another school campaign in a different district, and its relationship with the previous district becomes an indirect one in which the sales occur through the agents to serve future demand. Customers are unable to make warranty claims efficiently in such a scenario. Investing in larger systems provides the end-user with an added (potential) benefit of a reliable aftersales service experience, or at least the option not to continue repaying if a product breaks down.

In summary, we find that for rural off-grid Ugandans, a solar energy ladder hypothesis that suggests that users purchase SHSs after purchasing entry-level lights, and that user income or system affordability is the primary determining factor for the adoption of larger systems, does not hold. In addition, our findings indicate that the belief that reduced spending on traditional fuels and mobile phone charging plays a central role in financing large systems is not true either. The motivations for purchasing larger solar systems are not based mainly on financial returns but, instead, are driven by multiple factors including income, savings in energy spending, retailer proximity, effectiveness of direct marketing by retailers, demand for lights in turn determined by house and family size, attractive product-bundling options, flexible financing options, effective referrals, and demonstration effects.

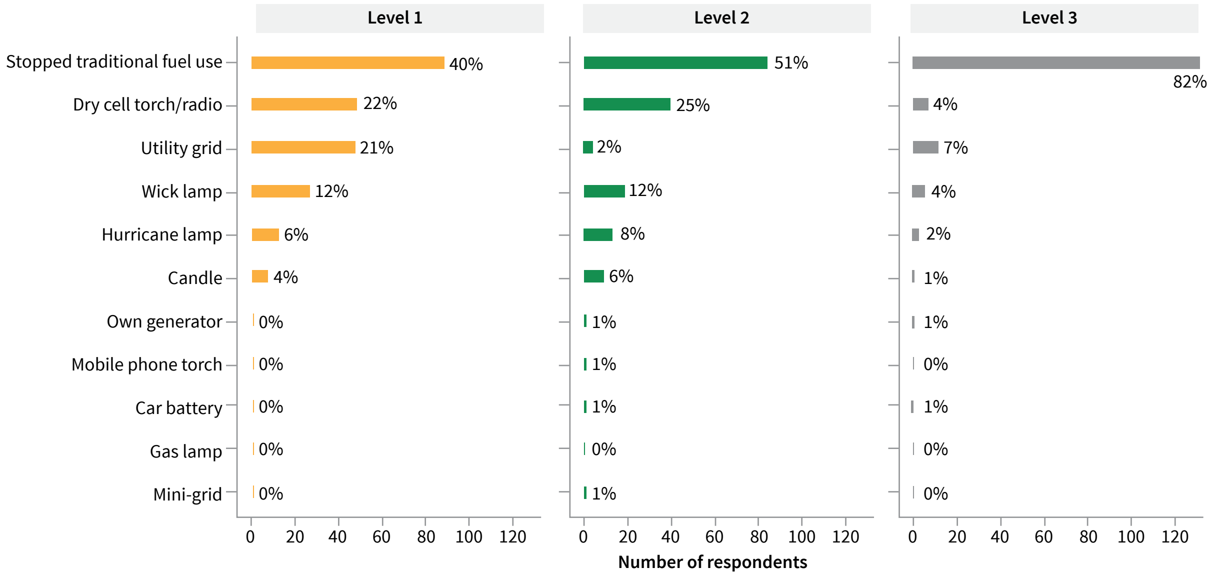
IS THE ADOPTION OF SOLAR TECHNOLOGY IN LINE WITH THE ENERGY TECHNOLOGY STACKING HYPOTHESIS?

Solar and non-solar technology stacking

The extent of solar and non-solar technology stacking is likely to be determined by the degree with which end-users substitute non-solar fuels with solar products. Figure 13 shows non-solar energy technologies being used by respondents at the time of the initial survey, May–June 2016. This was when all respondents had already invested in at least one solar system. The results indicate that many users reported that they were not using any non-solar energy device after purchasing a solar product, indicating perfect substitution. Users at Level 3 have the largest rate of perfect substitution (82 percent) following the adoption of solar technology. Level 3 users have access to the largest levels of energy service; consequently, their use of non-solar technologies for energy security purposes is limited. Other users continued to use technologies such as dry cell torches, kerosene lamps and candles, albeit in reduced quantities, following the adoption of a solar product, which is consistent with 'stacking' behaviour. Figure 13 shows the levels by which users have decreased their use of non-solar fuels. It is useful to classify determinants of fuel stacking other than income and affordability constraints into two categories: 'deliberative-choice' and 'constrained' fuel stacking.

Deliberative-choice stacking

We define deliberative-choice stacking as stacking behaviour observed when users use more than one energy fuel or technology at their will, without any external constraint. Such constraints could include a lack of availability of their primary fuel of choice or, for instance, the inability to use solar products on days when the sun is not shining enough. Deliberative stacking is often observed in the case of cooking fuels: due to cultural preferences and traditional methods of cooking, users are reluctant to abandon cooking with firewood or charcoal, or, on account of the low opportunity cost of collecting biomass-based fuel, they are reluctant to switch completely to costlier alternatives (Masera, Saatkamp and Kammen, 2000; Heltberg, 2004; Wuyuan, Zerriffi and Jiahua, 2010; Nansaior et al., 2011; Lee, 2013). Lisa Yu-Tin Lee (2013) found that upper-income households in Uganda continued to use charcoal for cooking. One reason for this was a preference for cooking traditional foods such as *matoke* (steamed green bananas) on charcoal. Giving up traditional cooking fuels involves a process of behaviour change, as cooking practices are closely interwoven with cultural preferences and lifestyles. Our observations do not suggest that 'deliberative-choice' stacking plays



Plot shows percentages within each level e.g. 40 percent of Level 1 respondents stopped using status quo fuels and technologies and shifted to solar off-grid product(s). Respondents can use more than one status quo fuel or technology.

Figure 13. Percentage of respondents using various non-solar energy fuels and technologies

a significant role in the adoption of off-grid solar technology. Stacking solar technologies with non-solar ones appears to be a case of 'constrained' solar stacking.

Constrained solar stacking

Several studies investigating the adoption of energy products have recognized that as incomes increase, many users want to replace incumbent fuels and technologies with cleaner, superior fuels and technologies through a form of perfect substitution. However, they are often unable to make this switch fully due to a lack of available modern fuel or to ensure energy security (i.e. they have a back-up option in the event that the newer fuel/technology becomes temporarily unavailable). Campbell, Vermeulen and Mabugu (2003) suggest that users often have a primary and a secondary fuel in their fuel mix. When the primary fuel becomes unavailable, users temporarily switch back to a lower-order fuel until the primary fuel is available again. Masera and colleagues (2000) also refer to constrained temporary inter-fuel substitution for reasons such as a lack of available modern fuel. We see a similar behaviour with the respondents in this study. Some of the study participants slowly increased their access to solar energy by making subsequent purchases over time. In parallel, they reduced their dependence on traditional fuels. This is because, despite consumer financing options, large SHSs continue to be expensive (see 'Motivation for purchasing solar home systems is not based on financial payback', above). As long as issues such as limited retailer proximity (described in 'Key prior experiences or information that influenced users', above) persist, and/or until users are completely able to substitute traditional fuels with newer fuels and technologies, users will be constrained to temporarily switch back to traditional fuels. Furthermore, substitution may never be perfect for all solar product users, as there may be a need to use traditional fuels on cloudy or rainy days or when users experience technical roblems with their solar products.

Solar-with-solar technology stacking

Solar-with-solar stacking occurs because the availability of a diverse range of commercial off-grid solar products allows users to fulfil their energy demand in parts. Despite the option for flexible financing, advanced solar systems (50Wp or more in panel size) can be prohibitively expensive (see Table 5) for Level 1 and Level 2 users. Some people who adopt solar products may start building their solar product portfolio with smaller systems. Solar product users also stack components of solar systems bought with a view to expand the current capacity of solar systems or to begin using AC appliances. Users start by fulfilling their most pressing energy needs, such as lighting and mobile charging, and then slowly add capacity to support the use of other appliances, such as TV sets, purchase new appliances and expand the hours of use of existing appliances. Furthermore, the promise of electricity generated by solar products helps unlock latent energy demand and leads to investments that enable the expansion of systems to power more and more appliances over time.

SOLAR-WITH-SOLAR PRODUCT STACKING: WHO BOUGHT WHAT?

The first solar system bought by all users had at least one light point. In subsequent purchases of solar products, 91 percent of Level 1 users bought a product with at least one light, whereas no users bought a component such as a PV panel or a battery to expand the capacity of their current solar system. Level 1 users mostly own entry-level lights, typically with a solar panel size of 3Wp or less. These single-light systems do not allow an easy expansion of energy capacity. Batteries are often soldered onto the printed circuit board, and PV panels for the smallest lights are usually integrated into the system. In the case of Level 2 respondents, 58 percent of users bought a system with at least one light point, and 23 percent of users bought a component to expand the capacity of their solar system. In the case of Level 3 respondents, 41 percent of users bought a system with at least one light point, and 14 percent of users bought a component such as a solar panel or battery to expand the system's capacity. Level 2 systems are mostly 10–17Wp, while Level 3 systems have solar panels rated at 50Wp or more. Given the greater need to expand hours of use and energy service, a larger proportion of Level 2 users invested in more light points and system expansion (see Table 5).

SUBSEQUENT PURCHASE ANALYSIS: INSIGHTS FOR SOLAR PRODUCT RETAILERS

We looked at rates of subsequent adoption of solar products across the three levels of solar energy access and evaluated preferences for dealer and financing method for subsequent purchases. The motivation for the analysis was to determine how, after purchasing at least one solar product, the user's increased awareness of off-grid solar technology use translated into choices for selecting:

Table 5. Common solar energy products bought by subsequent purchasers (respondents who bought at least one other solar energy product between the initial (May–June 2015) and the second (February 2017) rounds of surveys

LEVEL OF SOLAR ENERGY ACCESS	OVERALL ACTUAL PURCHASERS*	SYSTEMS WITH LIGHTS†	OVERALL ACTUAL ADOPTION RATE	LIGHT ADOPTION RATE	COMPONENTS BOUGHT TO EXPAND CURRENT SOLAR SYSTEM‡	SYSTEM EXPANSION RATE
Level 1	44	40	22%	91%	0	0%
Level 2	26	15	18%	58%	6	23%
Level 3	22	9	15%	41%	3	14%
Total	**92**	**64**	**18%**	**70%**	**9**	**10%**

*Note: * Overall actual purchasers: Respondents who bought a solar energy product between the initial (May–June 2015) and second (February 2017) rounds of surveys.*

† Systems with lights: Respondents who bought a solar system that had at least one light.

‡ Components bought to expand current solar system: Respondents who bought a panel and/or a battery to increase the hours of service of an existing solar system.

- the solar product company (or dealer): This analysis was done to understand stickiness for the dealer that sold the user their first product, dissatisfaction with the current dealer (if any), and user preferences regarding the types of solar products that may be considered for future purchases; and
- the financing method: This analysis was used to determine which type of financing method (e.g. cash purchase, PAYG or micro-credit) users would prefer for their next purchase, considering their experience with the first purchase.

During the initial survey, conducted in May and June 2016, we asked respondents if they planned to purchase solar products in future. We also collected data on the time-frame they had in mind for this purchase, and details about the end-uses such a solar product would power, where they would purchase the product and how they would finance it. We used these data to understand the planned adoption rate. During the second round of surveys conducted in February 2017, we collected data on the solar product purchases made between the initial and second rounds of surveys. The actual purchase data were compared with the planned purchase data to understand differences between the planned and actual adoption rates. These results are discussed below, and we also describe the results for user preferences for subsequent purchases of solar products.

ADOPTION RATES

The results for the planned adoption rate, the actual adoption rate and the overall actual adoption rate (i.e. the adoption rate considering all respondents who bought a solar product between the initial and second rounds of surveys) are recorded in Table 6 (see the text below Table 6 for definitions of each). Key insights from this analysis are as follows.

- For subsequent purchases of solar energy products, impulse buying is low, and planned buying is high. Overall, 86 percent of total purchases of solar products between the initial and second rounds of surveys were made by respondents who had indicated that they planned to purchase a solar product. Figure 14 shows a near overlap between the planned-actual and overall adoption rates.
- End-users who indicate an interest in purchasing solar products constitute a pool of promising upsell opportunities.
- The sales-to-lead conversion rate is high, at between 17 percent and 23 percent for all respondent levels.
- Overall, 20 percent of respondents who had planned to make subsequent purchases did so within seven or eight months.

Table 6. Planned and actual adoption rates of solar products between the initial (May–June 2016) and second (February 2017) rounds of surveys

	PLANNED ADOPTION RATE	PLANNED-ACTUAL ADOPTION RATE	OVERALL ACTUAL ADOPTION RATE
Level 1	75%	23%	22%
Level 2	90%	19%	18%
Level 3	76%	17%	15%
Total	**80%**	**20%**	**18%**

Note: Planned adoption rate: Respondents who indicated during the initial survey that they planned to purchase additional solar products. Planned-actual adoption rate purchasers: Respondents within the pool who planned to purchase a product at the time of the initial survey and did purchase a solar product between the initial and second rounds of surveys. Overall actual adoption rate: Total proportion of respondents who purchased solar products between the initial and second rounds of surveys.

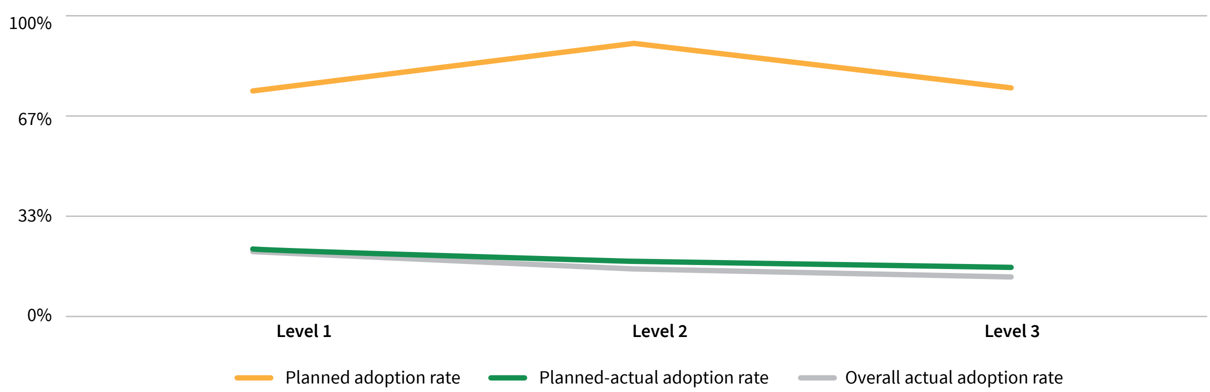


Figure 14. Planned and actual adoption rate of solar products between the initial (May–June 2016) and second (February 2017) rounds of surveys

DEALER STICKINESS

Preferences regarding the product vendor (or dealer) in subsequent purchases of solar products are recorded in Table 7. The results show that a substantial majority of Level 2 and Level 3 respondents prefer their current dealer. In 'User plans for subsequent purchases' (below), we illustrate that the users do not prefer their current dealers for subsequent purchases for reasons related to flexible consumer financing; instead, they prefer to pay for the full cost of a system upfront. Key insights from this analysis are as follows.

- Dealer stickiness for Level 1 respondents is lower than for Level 2 and Level 3 respondents. Approximately 66 percent of respondents indicated that they were not sure which retailer they would use when purchasing their next solar product. This could be due to a combination of factors, such as dissatisfaction with the product itself, or with aftersales service from their current dealer, a lack of sustained access to the agents who sold them their solar lamps, an interest in larger products that their current dealer does not sell, or other factors.
- Dealer stickiness is considerably higher, above 70 percent, for Level 2 and Level 3 respondents. However, according to the responses, this is not because of the credit financing options these dealers provide. Nearly all (97 percent) of total respondents indicated that they preferred to make

Table 7. Preferred dealers for subsequent purchases as reported at the time of the initial survey (May–June 2016)

LEVEL 1	COUNT	%
Not sure	112	66%
SunnyMoney	41	24%
Unknown solar shop	5	3%
Electronics shop	4	2%
Fenix	3	2%
SolarNow	2	1%
Solar Solutions	1	1%
Pallisa Teachers' SACCO	1	1%
Utility grid	1	1%
Total	**170**	**100%**

LEVEL 2	COUNT	%
Fenix	111	74%
Not sure	36	24%
Unknown solar shop	1	1%
SolarNow	1	1%
Utility grid	1	1%
Total	**150**	**100%**

LEVEL 3	COUNT	%
SolarNow	90	73%
Not sure	28	23%
Soltec	1	1%
M-Kopa	1	1%
Sunshine Solar	1	1%
Construct solar systems	1	1%
Solar Solutions	1	1%
Total	**123**	**100%**

Table 8. Plans for subsequent purchases of energy products of Level 1 respondents

LEVEL 1 (SUNNYMONEY): 170 OF 226 RESPONDENTS SAID THEY HAD PLANS FOR PURCHASING AT LEAST ONE OTHER ENERGY PRODUCT				
Preferred dealer*	**Preferred financing method****	**Available sales method of preferred dealer*****	**Count**	**%**
Not sure	Upfront payment with personal savings	Not sure	95	56%
		Upfront payment/cash basis	12	7%
		Credit-based sale	2	1%
		PAYG	1	1%
	Loan with interest	Not sure	2	1%
SunnyMoney	Upfront payment with personal savings	Upfront payment/cash basis	19	11%
		Not sure	18	11%
		Credit-based sale	2	1%
		PAYG	1	1%
	Not sure	Not sure	1	1%
Unknown solar shop	Upfront payment with personal savings	Not sure	3	2%
		PAYG	2	1%
Electronics shop	Upfront payment with personal saving	Not sure	3	2%
		Upfront payment/cash basis	1	1%
Fenix	Upfront payment with personal savings	PAYG	3	2%
SolarNow	Upfront payment with personal savings	Not sure	1	1%
			1	1%
Solar Solutions	Upfront payment with personal savings	Not sure	1	1%
Utility grid	Upfront payment with personal savings	Upfront payment/cash basis	1	1%
Pallisa Teachers' SACCO	Upfront payment with personal savings	Not sure	1	1%
Total			**170**	**100%**

*Note: * Preferred dealer: Dealer from whom respondents planned to buy their next solar product.*
*** Preferred financing method: How respondents prefer to finance their next purchase of a solar product.*
**** Available sales method of preferred dealer: Respondents' understanding of the financing options available from their preferred dealer.*

subsequent purchases by using personal savings to pay for the full cost of the system upfront (see 'User plans for subsequent purchases' (below) for further discussion).

- Successful direct marketing has a role to play in high dealer stickiness. Dealer stickiness is high, in part, because of the low density of solar product dealers. Most dealers are in central towns or alongside highways, and they seek out customers through direct marketing. Many buyers may not have access to or be familiar with dealers other than the one from which they made their original purchase.
- Significant upsell opportunities exist for dealers within their existing customer base.

USER PLANS FOR SUBSEQUENT PURCHASES

Respondents who planned to make further purchases of energy products at the time of the initial survey (May–June 2016) were asked about their preferences regarding the dealer from whom to make the purchase, the financing method, and the financing options available from their preferred dealer (see Tables 8, 9 and 10). The results in the dealer stickiness analysis show that most Level 2 and Level 3 respondents prefer their current dealer for subsequent purchases.

- Level 1 respondents: As noted in 'Dealer stickiness' (above), 66 percent of Level 1

Table 9. Plans for subsequent purchases of energy products of Level 2 respondents

<table>
<tr><th colspan="5">LEVEL 2 (FENIX/PAYG): 150 OF 166 RESPONDENTS SAID THEY HAD PLANS FOR PURCHASING AT LEAST ONE OTHER ENERGY PRODUCT</th></tr>
<tr><th>Preferred dealer</th><th>Preferred financing method</th><th>Available sales method of preferred dealer</th><th>Count</th><th>%</th></tr>
<tr><td rowspan="5">Fenix</td><td rowspan="2">Upfront payment with personal savings</td><td>PAYG</td><td>96</td><td>64%</td></tr>
<tr><td>Not sure</td><td>12</td><td>8%</td></tr>
<tr><td>Borrow money - loan without interest</td><td>PAYG</td><td>1</td><td>1%</td></tr>
<tr><td>Loan with interest</td><td>PAYG</td><td>1</td><td>1%</td></tr>
<tr><td>Not sure</td><td>Not sure</td><td>1</td><td>1%</td></tr>
<tr><td rowspan="4">Not sure</td><td rowspan="3">Upfront payment with personal savings</td><td>Not sure</td><td>33</td><td>22%</td></tr>
<tr><td>PAYG</td><td>1</td><td>1%</td></tr>
<tr><td>Upfront payment/cash basis</td><td>1</td><td>1%</td></tr>
<tr><td>PAYG</td><td>Not sure</td><td>1</td><td>1%</td></tr>
<tr><td>SolarNow</td><td>Upfront payment with personal savings</td><td>PAYG</td><td>1</td><td>1%</td></tr>
<tr><td>Unknown solar shop</td><td>Upfront payment with personal savings</td><td>Not sure</td><td>1</td><td>1%</td></tr>
<tr><td>Utility grid</td><td>Upfront payment with personal savings</td><td>Upfront payment/cash basis</td><td>1</td><td>1%</td></tr>
<tr><td colspan="3">Total</td><td>150</td><td>100%</td></tr>
</table>

respondents are not sure which retailer they will use to purchase their next solar product (see Table 8).

- Level 2 respondents: Nearly all (98 percent) of Level 2 respondents either want to purchase from the same dealer (Fenix) or have not made up their mind about the dealer yet. Despite being familiar with mobile money payment processes, PAYG users indicated that they do not prefer PAYG-based financing for subsequent purchases (see Table 9). PAYG financing is a strong enabler of Level 2 access to energy for first-time purchasers, yet there is user dissatisfaction with flexible financing approaches, especially for subsequent purchases. Further research is warranted to understand this apparent contradiction.
- Level 3 respondents: Almost all (96 percent) of Level 3 respondents (SolarNow customers) reported that they either want to purchase from SolarNow or have not made up their mind about the dealer yet. A similar proportion (95 percent) of Level 3 respondents want to use personal savings to cover the full cost of the system upfront (see Table 10).

SUMMARY OF SUBSEQUENT PURCHASE ANALYSIS

In summary, respondents expressed a strong preference for upfront payments using personal savings (see Table 11). Overall, 97 percent of respondents across the three levels indicated that they wanted to use personal savings to cover the full cost of the system upfront. Users make substantial savings in energy spending on energy fuel by switching to solar. However, as discussed in 'Motivation for purchasing solar home systems is not based on financial payback' (above), these savings are not enough to recover the full cost of their SHSs. Dealer stickiness is significant (over 70 percent) for Level 2 and Level 3 respondents, but not because of the credit financing option these dealers provide. As an example, while dealer stickiness for Fenix is high (75 percent), and most (90 percent) of their customers indicated an interest in making a subsequent purchase at the time of the initial survey, none preferred PAYG financing for their next purchase. This does not mean that people will not use PAYG financing in the future, but it does indicate dissatisfaction with this payment approach.

Table 10. Plans for subsequent purchases of energy products of Level 3 respondents

LEVEL 3: SOLARNOW: 123 OF 162 RESPONDENTS SAID THEY HAD PLANS FOR PURCHASING AT LEAST ONE OTHER ENERGY PRODUCT				
Preferred dealer	**Preferred financing method**	**Available sales method of preferred dealer**	**Count**	**%**
SolarNow	Upfront payment with personal savings	Credit-based sale	77	63%
		Not sure	6	5%
		Upfront payment/cash basis	2	2%
		PAYG	1	1%
	Loan with interest	Both upfront payment/cash basis and credit-based sale	1	1%
		Credit-based sale	1	1%
		Not sure	1	1%
		Credit-based sale	1	1%
Not sure	Upfront payment with personal savings	Not sure	19	15%
		Credit-based sale	7	6%
	Loan with interest	Credit-based sale	1	1%
	Not sure	Credit-based sale	1	1%
Construct solar systems	Upfront payment with personal savings	Not sure	1	1%
M-Kopa	Upfront payment with personal savings	Not sure	1	1%
Solar Solutions	Upfront payment with personal savings	Not sure	1	1%
Soltec	Upfront payment with personal savings	Credit-based sale	1	1%
Sunshine Solar	Upfront payment with personal savings	Credit-based sale	1	1%
Total			**123**	**100%**

Dealer stickiness for SunnyMoney is lower, at 24 percent, than for Level 2 and Level 3 users. SunnyMoney customers' preference to purchase from a different 'known' dealer is relatively high at 9 percent when compared with Level 2 and Level 3 respondents. The fact that SunnyMoney markets its products through short-lived campaigns conducted once a year in villages, has limited options for larger solar systems and does not have a consistent sales touch-point likely plays a role in its low dealer stickiness. Lastly, off-grid solar technologies, where available, are the most preferred option for energy service delivery. Preferences to purchase non-solar energy products or to obtain a utility grid connection are low. Only two respondents planned to gain access to the utility grid. Almost all respondents are moving towards greater substitution of status quo energy fuels and technologies by off-grid solar energy solutions.

Table 11. Summary table for subsequent purchase analysis

KEY METRICS	LEVEL 1	LEVEL 2	LEVEL 3
Preference for upfront payment using personal savings	98%	97%	95%
Dealer stickiness	24%	74%	73%
Preference to purchase from a different 'known' dealer	9%	2%	4%
Preference for PAYG as financing method	0%	0%	0%
Preference to purchase non-solar energy products or take utility grid connection	<1%	<1%	0%

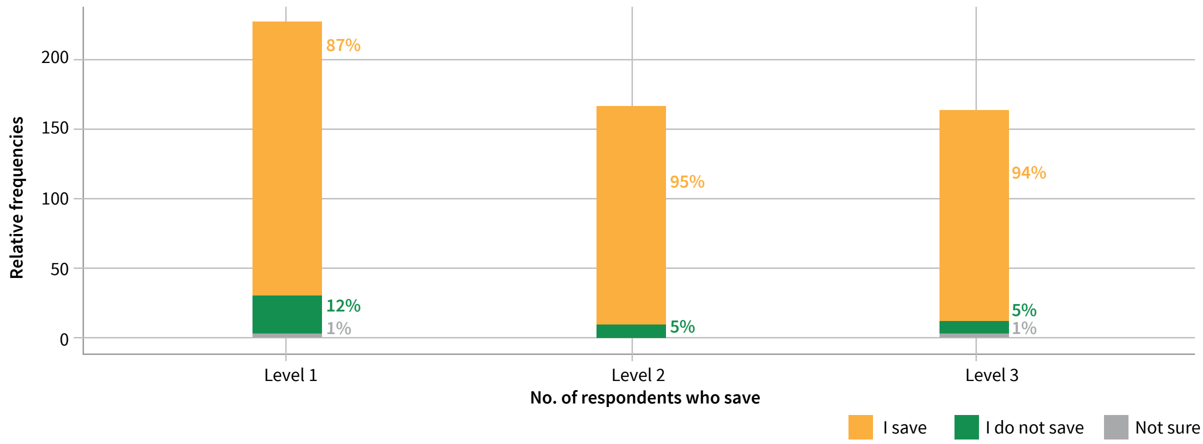


Figure 15. Number of survey respondents who do and do not save by purchasing a solar product (by group level)

IMPACT OF DIGITAL SOLAR PAYMENTS ON DIGITAL FINANCIAL INCLUSION

In the final section of this report, we explore the ability of PAYG systems to drive digital financial inclusion. To explore this question, we have looked at both self-reported data from respondents during surveys and mobile money use data obtained from MTN Uganda. The engagement with MTN Uganda was facilitated by partners at the United Nations Capital Development Fund (UNCDF).

SELF-REPORTED MOBILE MONEY USE DATA ANALYSIS

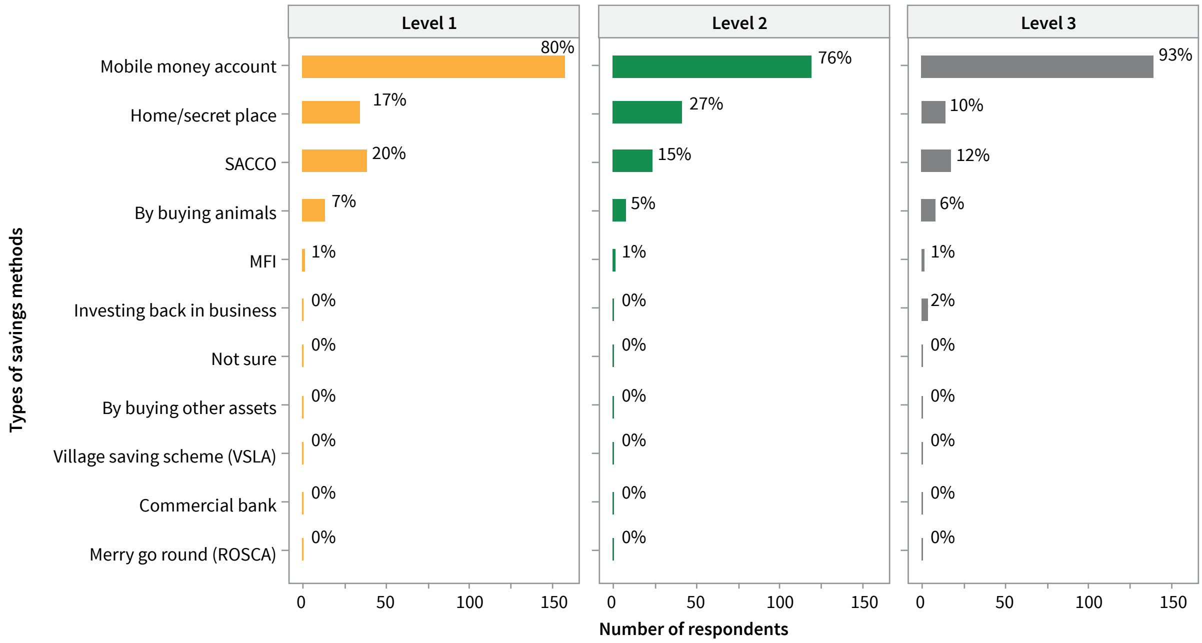
We collected data about the various savings options used by respondents across the three levels of solar energy access. These data helped us compare observations between PAYG respondents and non-PAYG respondents (see Figure 16). We also used information about awareness and levels of use of mobile money services to examine differences in use between PAYG users and non-PAYG users. If detected, greater awareness and levels of use among PAYG users than among non-PAYG users could provide a first indication of causality between the use of PAYG solar products and digital financial inclusion.

We found that a substantial majority of respondents across the three levels of solar energy access saved money (Figure 16) and used mobile money accounts for savings[14] (see Figure 17). More than 85 percent of respondents across all three levels save, and more than 75 percent of respondents across all three levels use mobile money to save. The proportion of users using mobile money for savings is similar across Levels 1 and 2 (80 percent and 76 percent, respectively), and substantially higher for Level 3 users (93 percent). We know from Figure 9 that the incomes of Level 1 and Level 2 users are similar and that Level 3 users have higher incomes. While other factors may be responsible for this apparent difference, it is unsurprising that a greater number of high-income households would tend to use formal means of saving. These results are reinforced in the actual mobile money use data discussed in the next section. In what follows we look at other linkages between PAYG solar use and digital financial inclusion.

To explore 'additionality'—users who were newly digitally included via mobile money accounts they may have opened as a result of adopting PAYG solar devices—we looked at the factors that motivated the respondents to adopt mobile money accounts (see Figure 17).

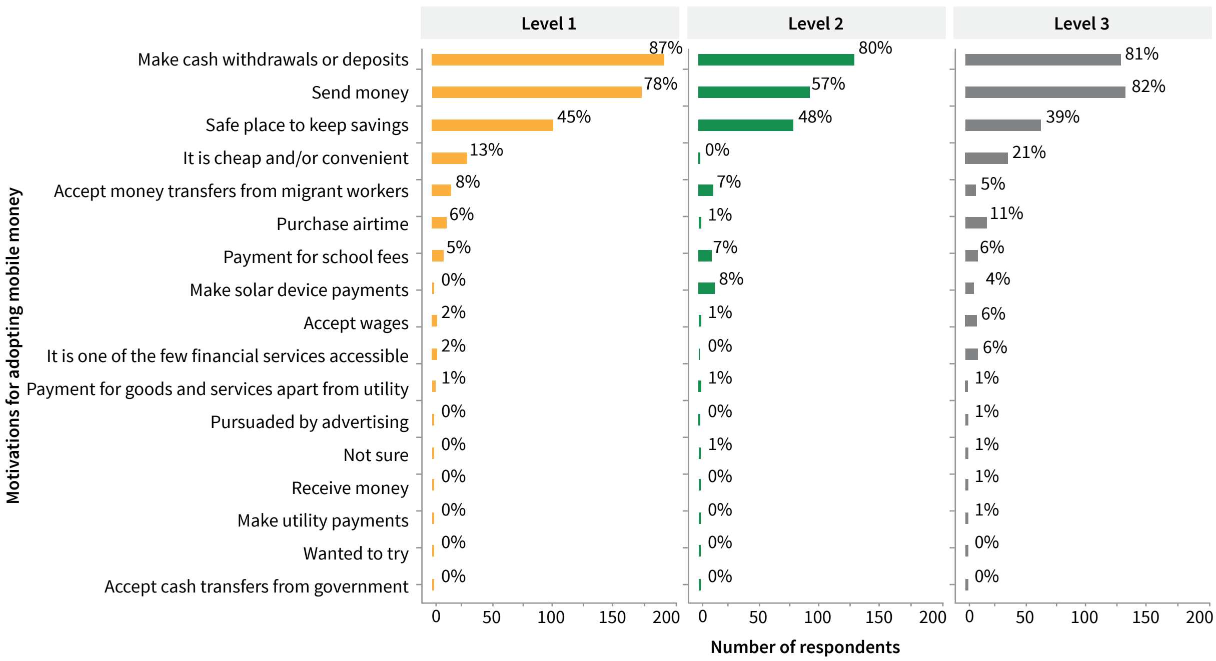
14 It should be noted that these data were collected (in May–June 2016) before MTN launched the MoKash savings option. It is likely that MoKash has prompted more Ugandans to save using mobile money since its launch.

The results indicate that making solar payments was not the primary motivation for adopting mobile money accounts for PAYG customers. The primary motivations for subscribing to mobile money accounts are similar across the three levels and include making cash withdrawals or deposits, sending money and having access to a secure place to keep savings. It should be noted that there can be several competing mobile money services, and a user may have access to one or more of these services at the time of purchasing a PAYG device. When studies



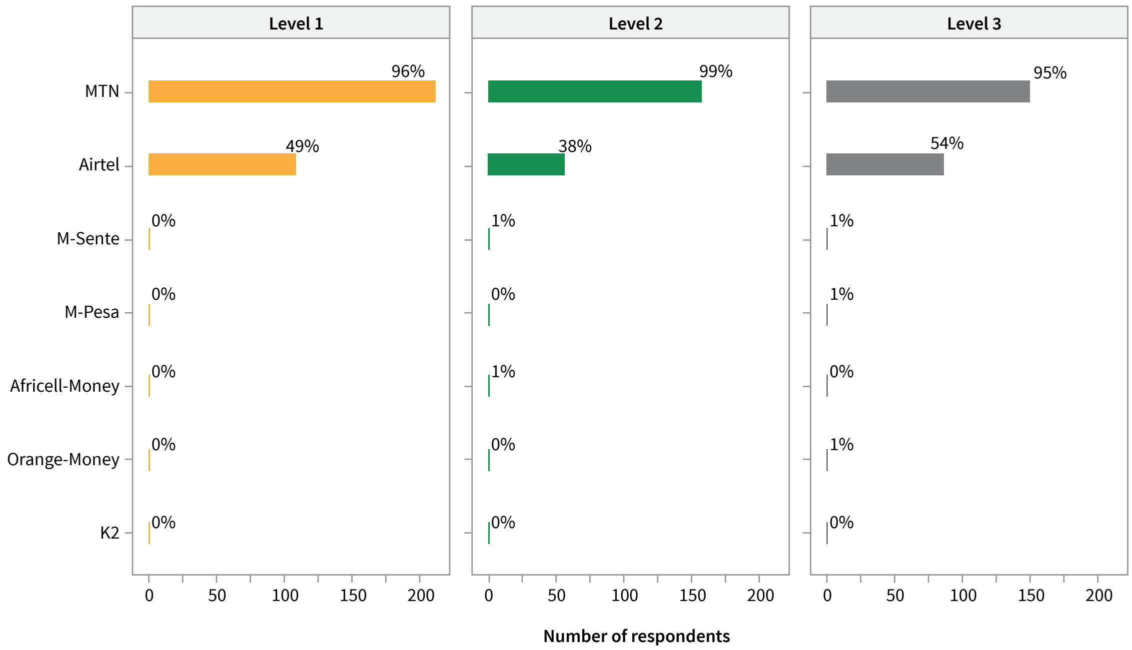
Plot shows within-level percentage. E.g. 80 percent of respondents in Level 1 use a mobile money account to save money. Respondents can employ more than one saving method.

Figure 16. Savings tools used by respondents



Plot shows percentages within each level e.g. 87 percent of respondents within Level 1 subscribed to a mobile money account to make cash withdrawals and deposits. Respondents can use more than one motivation.

Figure 17. Motives for subscribing to a mobile money account



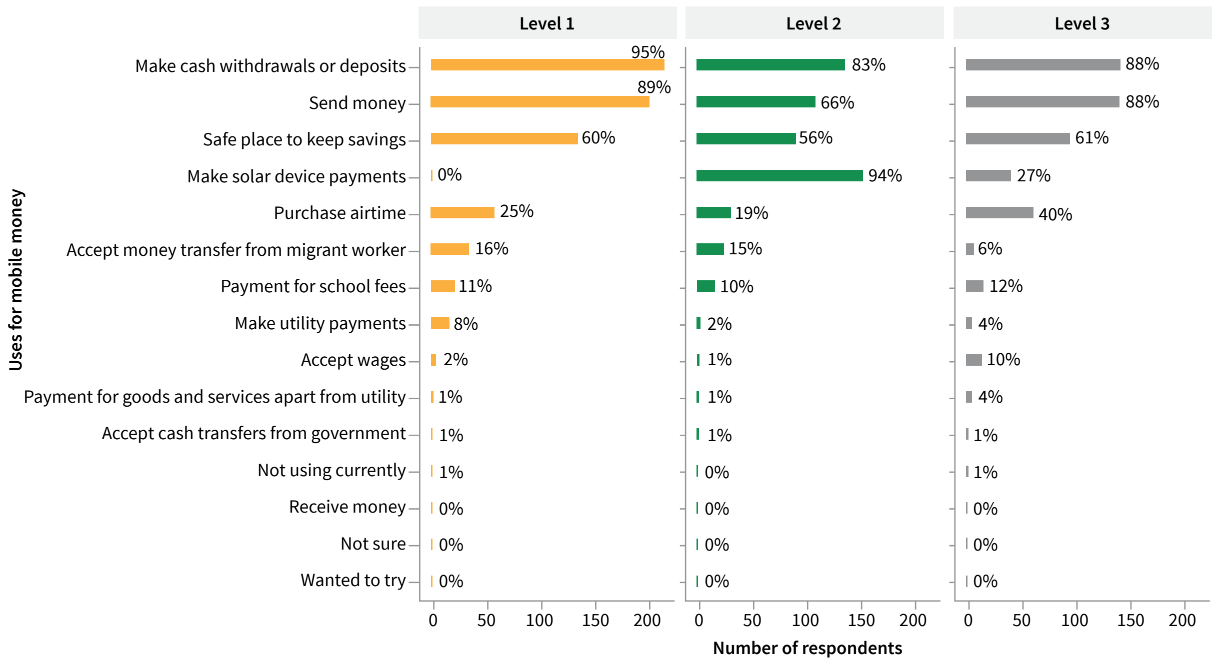
Plot shows within-level percentage. E.g. 96 percent of respondents in Level 1 have access to the MTN Uganda mobile money service. Respondents can have more than one mobile money service.

Figure 18. Mobile money accounts being used by respondents

that attribute digital financial inclusion to the use of a PAYG device talk about the creation of new mobile money accounts, they tend to focus on the benefits arising to the mobile money operator with whom the PAYG company has a bill pay account partnership. Given the exclusivity of such partnerships, a user must open the mobile money account with the operator in question before they can start to use the solar device. Such users could be existing users of mobile money accounts of other operators at the time of purchasing the PAYG device, just not of the prescribed mobile money service. To attribute true additionality, it is important to see whether users were using other mobile money services at the time of adopting a PAYG device. The two main mobile money services used in Uganda are MTN Uganda and Airtel Money (see Figure 18). Depending on the level of solar product adopted, 95–99 percent of users have an MTN Uganda mobile money account, and 38–54 percent of users have an Airtel Money account. It is certainly possible that adoption of the Fenix system led to new MTN Money accounts for users who were previously using Airtel Money, but this would not represent true additionality.

Table 12. Respondents for whom mobile money transactions data are available

LEVEL OF SOLAR ENERGY ACCESS	SAMPLE SIZE	RESPONDENTS WITH MTN MOBILE MONEY ACCOUNTS	%
Level 1	226	175	77%
Level 2	166	154	93%
Level 3	162	129	80%



Plot shows percentages within each level e.g. 95% respondents within Level 1 use mobile money to make withdrawals and deposits. Respondents can use more than one use for mobile money service.

Figure 19. Various mobile money services being used by respondents

We also looked at the various mobile money services being used by respondents at all three levels to investigate whether differences existed (see Figure 19). Use of various mobile money services is also consistent across the three levels, provided that one ignores the solar payment use by respondents who were PAYG customers (i.e. Level 2). The main uses of mobile money reported by study participants are core mobile banking services such as sending money and making withdrawals and deposits.

ANALYSIS OF MOBILE MONEY TRANSACTIONS

Based on the self-reported data from study participants, we do not observe a clear relationship between PAYG device use and digital financial inclusion. To further validate these results we further analysed MTN mobile money transaction records which were provided to us by the mobile money provider, after having asked the interviewees for their informed consent (see Table 12).

We analysed four metrics of MTN mobile money account holders for the period from January 2015 to March 2017, looking at transaction value (TXVA), average revenue per user (ARPU), and total amount sent and received. For simplicity, we show results for total transaction value only. The results obtained from analysis of ARPU, sent funds and received funds mimic the results obtained from analysis of transaction value data.[15]

Total transaction value of mobile transactions

Figure 20 shows that mobile money transaction values increase with the level of solar energy access. The difference in total transaction value for Level 1 and Level 2 off-grid solar buyers is substantially lower than that for Level 3 buyers. For example, for Levels 1 and 2, the annual transaction value for 75 percent of respondents varies between $0 and $1,800, whereas for Level 3 the annual transaction value for 75 percent of respondents has a much larger spread at $0–4,000 for Year 1 and $0–4,600 for Year 2. Figure 21 details mobile money transactions by solar energy access levels and income quartiles

15 The full analysis is available upon request.

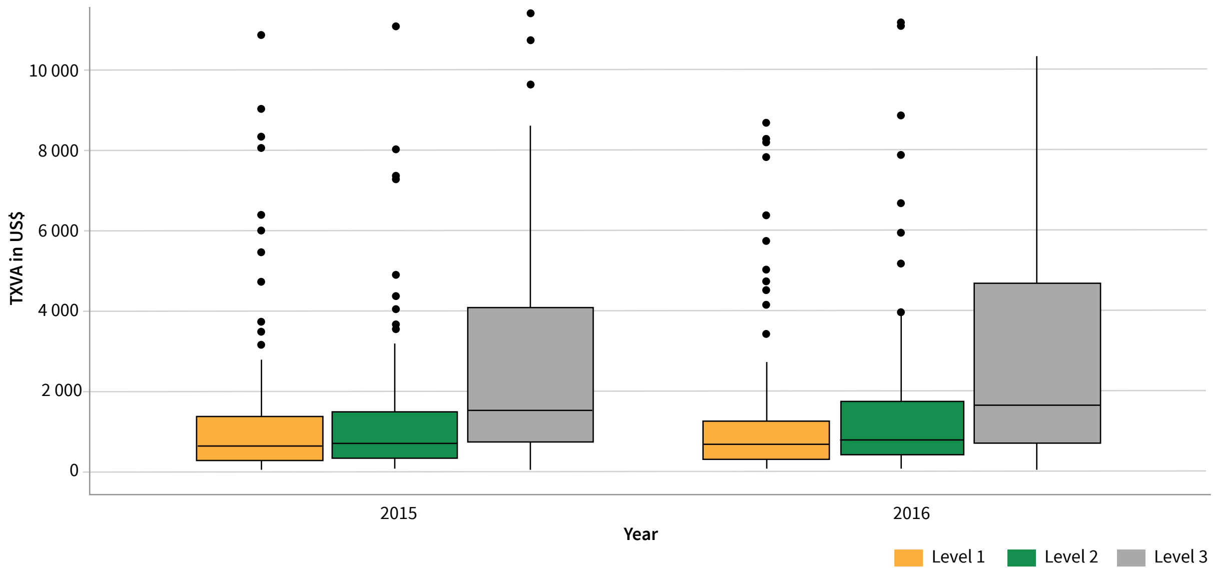


Figure 20. Mobile money transactions shown separately for 2015 and 2016 by solar energy access level

Note: The black line in the middle of each coloured rectangle indicates the median transaction value for that level. The graph shows transaction value up to about $11,500 per year to focus attention on the transaction levels associated with most customers. Some outliers have been excluded, as a few respondents had annual transaction value amounts exceeding $60,000.

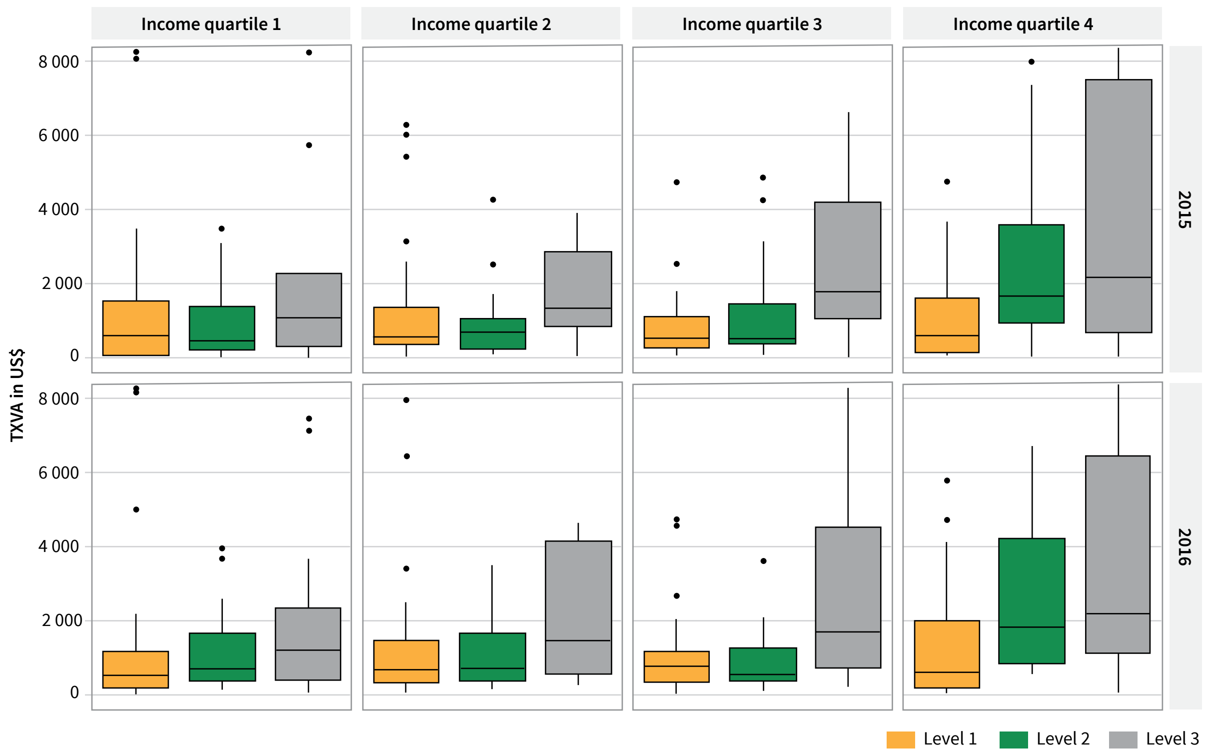


Figure 21. The data in Figure 20 are further split by income quartile

Note: The black line in the middle of each coloured rectangle indicates the median transaction value for that level. The graph shows transaction value values up to about $8,000 per year to focus attention on the majority of users. Some outliers have been excluded, including for respondents with transaction value amounts exceeding $60,000 per year.

for 2015 and 2016. We find Level 1 and level 2 respondents hardly showing any increase in annual transaction values across the income quantiles; however, Level 3 respondents show an increasing trend of annual transaction value with income over all four income quartiles.

We present a time series of median transaction values per quarter in Figure 22. We also show the consolidated median transaction value for 2015 and 2016 in Figure 23. These figures confirm the difference in transaction volume observed between Level 1 and Level 2 respondents, on the one hand, and Level 3 respondents on the other. Level 2 (PAYG) respondents show a greater volume of mobile money activity only in the fourth income quartile, which reflects a relationship between income and the value of mobile money transactions. The data do not suggest a relationship between use of a PAYG device and increased volume of mobile money transactions.

We conclude that the relationship between the level of mobile money activity and income is strong and merits further investigation. We do not observe any meaningful relationship between use of a PAYG device and digital financial inclusion.

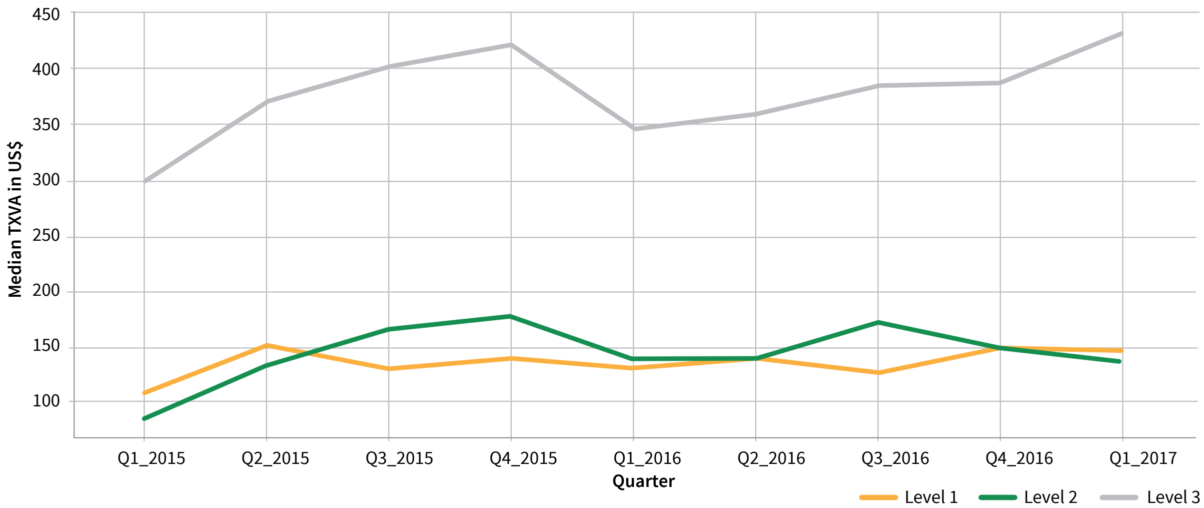


Figure 22. Median total transaction value by level of solar energy access by quarter

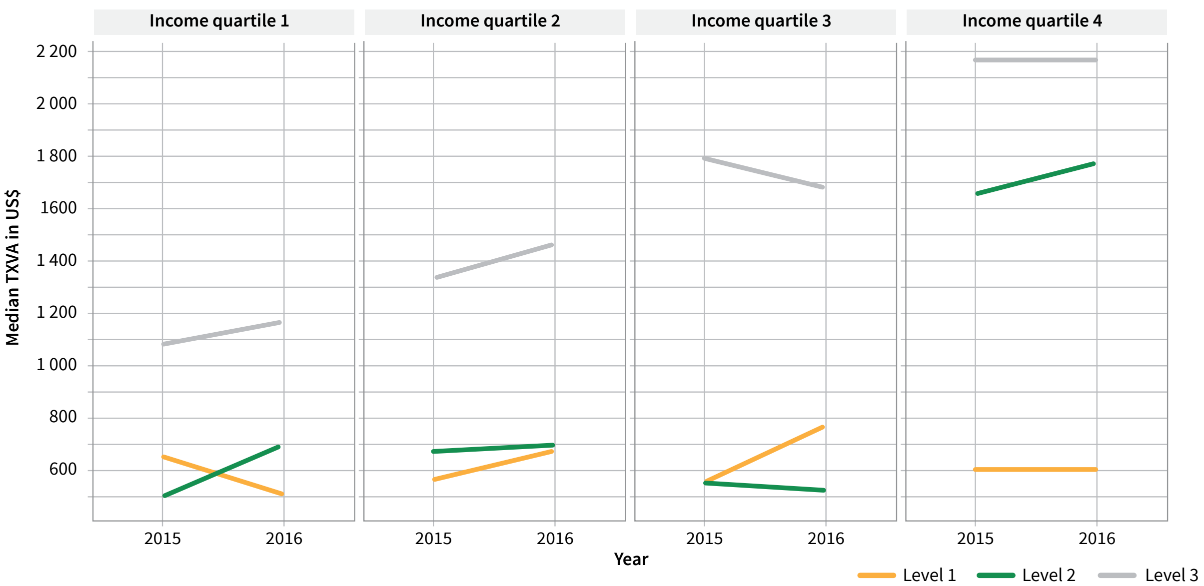


Figure 23. Median total transaction value by level of solar energy access in 2015 and 2016 broken down by income quartile

6 CONCLUSION, RECOMMENDATIONS FOR FURTHER RESEARCH AND NEXT STEPS

KEY RESULTS

THE ENERGY LADDER HYPOTHESIS

Our results do not support the existence of a simple, linear energy ladder for off-grid solar products in rural Uganda, in which the adoption of small, low-cost products precedes the purchase of larger systems. Most buyers, including those who had purchased larger systems, reported that the product they bought in 2015 represented their first off-grid solar product/system purchase (see Table 2). Level 2 and Level 3 users reported that they were motivated to purchase a larger solar system as their first purchase because they wanted an affordable system with multiple light points and an attractive product bundle (e.g. the ability to power multiple appliances). A substantial majority of Level 2 and Level 3 respondents purchased multi-light SHSs because they needed or wanted more than one light because they had a big family or a big house. For Level 3 users, an attractive product bundle is the second most important motivating factor, as advanced solar systems at Level 3 allowed more customization. Flexible payment terms and affordability were reportedly greater incentives for Level 2 users than for Level 3 users (see Figure 8). The income levels of Level 1 and Level 2 respondents were similar, and those of Level 3 users were substantially higher. Since Level 3 systems are larger—at 50Wp or more in solar panel size—it is not surprising that the households that purchase them have higher incomes. At the same time, Level 2 systems are much larger (typically 10–17Wp in solar panel size) than entry-level systems at Level 1 (typically less than 3Wp). Given that users at these two levels fall into similar income groups, flexible financing options play an especially important role in increasing affordability for Level 2 users, although it is also important for Level 3 users. However, the higher levels of energy service associated with the mini-SHSs came at a price, as Level 2 adopters invested much more in their systems and did not experience the types of short-term return on investment seen by Level 1 adopters (see Table 4).

The high degree of influence of retail sales agents on product purchases may be linked to the fact that rural Uganda has some characteristics of a greenfield market for off-grid solar products. Many customers interact with a limited number of sales agents before making a purchase. Furthermore, field observations indicate that their product choices are typically restricted to vendors who have nearby sales outlets or companies that send direct marketing sales agents to their village or home. In other words, many people who purchased a solar product may have bought it from the first compelling sales agent they encountered. This outcome is consistent with the results shown in Table 2, which indicate that most study participants were buying their first solar product when they made their purchase in 2015. Other important factors that influenced purchases included referrals by friends, family and thought leaders such as teachers or priests, which contributed to 26 percent of purchases, and demonstration effects, which contributed to 19 percent of purchases.

THE FUEL STACKING HYPOTHESIS

It is too early to say whether those who adopted solar lamps in 2015 (Level 1 adopters) will eventually purchase a larger system, but as of February 2017, relatively few had done so. Rather, many had purchased additional solar lamps in an adoption pattern that is consistent with a solar version of the product stacking model. Roughly 60 percent of Level 1 adopters reported a small degree of continued use of traditional energy sources such as dry cell batteries, kerosene lamps and candles, and 40 percent indicated that they had stopped using all such technologies after purchasing a solar light (see Figure 13). Continued use of traditional sources declined as the solar system size increased, with over 80 percent of SHS adopters reporting that they no longer used such energy sources. Hence, we see both: (a) stacking of different solar devices because the availability of a diverse range of commercial off-grid solar products allows users to fulfil their energy demand; and (b) a constrained stacking of solar technologies with traditional fuels for energy security purposes. That is, users slowly increase access to solar energy by making subsequent purchases and, in parallel, reduce their dependence on traditional fuels.

PREFERENCES FOR SUBSEQUENT PURCHASES OF SOLAR SYSTEMS

Many study participants gained access to off-grid solar products using flexible finance mechanisms, but they indicated an interest in using cash purchases to expand their level of access in the future. Nearly all respondents (97 percent) indicated that they would prefer to use personal savings to pay the full cost of a system upfront for their next purchase. This suggests a degree of frustration with flexible payment schemes despite the affordability benefits they offer.

It is notable that while users achieve savings in spending on fuel by switching to solar, these savings are not sufficient to cover the full cost of SHSs for Level 2 and Level 3 adopters (see 'Motivation for purchasing solar home systems is not based on financial payback' in Section 5).

Dealer stickiness is significant, at more than 70 percent for Level 2 and 3 respondents. High dealer stickiness for these solar adopters does not, however, appear to be related to a preference for the credit financing option these dealers provide. Dealer stickiness for Level 1 adopters of SunnyMoney products is lower than for Level 2 and Level 3 users, at 24 percent. Level 1 users' preference to purchase from a different 'known' dealer is also higher than for Levels 2 and 3, at 9 percent (see Table 13). The fact that SunnyMoney markets its products through short-lived campaigns conducted once a year in villages and does not have a permanent sales touch-point appears to play a role in its low dealer stickiness, as well as, potentially, its higher proportion of purchases of entry-level solar products. Lastly, off-grid solar technologies, where available, are the preferred option for energy service delivery. There was a low level of preference to purchase non-solar energy products, and few respondents indicated plans to pursue a utility grid connection. The latter was mostly because of a lack of grid availability or reliable supply from the electricity grid. Almost all respondents are moving towards greater substitution of status quo energy fuels and technologies by off-grid solar energy solutions. Table 13 helps summarize the discussion in the subsection 'Subsequent purchase analysis: Insights for solar product retailers' in Section 5.

ADOPTION RATES

We observed low levels of impulse buying and a high degree of planned purchases for subsequent purchases of solar products among respondents. Overall, 86 percent of total purchases of solar products between the initial and second rounds of surveys were made by respondents who had indicated a plan to purchase a solar product. Figure 14 shows a near overlap between the planned-actual and overall adoption rates. End-users who indicate a plan to purchase solar

Table 13. Summary table for subsequent purchase analysis

KEY METRICS	LEVEL 1	LEVEL 2	LEVEL 3
Preference for upfront payment using personal savings	98%	97%	95%
Dealer stickiness	24%	74%	73%
Preference to purchase from a different 'known' dealer	9%	2%	4%
Preference for PAYG as financing method	0%	0%	0%
Preference to purchase non-solar energy products or take utility grid connection	<1%	<1%	0%

products constitute a promising pool of upsell opportunities. The sales-to-lead conversion rate is high, at 17–23 percent across the three user levels. Of those who said they planned to purchase a subsequent solar product, 20 percent did so within seven or eight months.

PAYG SOLAR DEVICES AND DIGITAL FINANCIAL INCLUSION

We conclude that the relationship between level of mobile money activity and income is strong and merits further investigation. We did not observe any meaningful relationship between use of a PAYG device and digital financial inclusion. Further, we did not observe any additionality within our respondent base—i.e. we did not observe users who were newly digitally financially included via mobile money by purchasing a PAYG solar device.

RECOMMENDATIONS FOR TOPICS FOR FURTHER RESEARCH AND NEXT STEPS

This research was designed as a pilot study with an objective of generating insights into these questions that could be used to inform further studies. It is with this view that the authors have documented recommendations for topics that merit further investigation.

FOCUS GROUP DISCUSSIONS THAT DIVE DEEP INTO FOLLOW-UP QUESTIONS FROM THIS STUDY

Our study relied heavily on phone surveys. These surveys were a cost-effective method for collecting information about consumer adoption histories for solar products, the use of various payment mechanisms and other associated data. However, it did not provide a useful platform for capturing information about the reasons for the various adoption decisions. An additional study involving group discussions or in-depth interviews (in person) to explore key follow-up questions that were identified during this analysis would be valuable. These discussions could include questions such as: a) why did Level 1 users not purchase larger systems as their first solar product purchase?; b) what caused PAYG customers dissatisfaction with that payment scheme?; and c) why did customers indicate a preference for cash payments over PAYG financing for subsequent purchases?

CONTINUING TO TRACK ADOPTION HISTORY

The authors built solar product adoption histories for approximately 500 respondents based mainly in the districts of Luwero in south-central Uganda and Pallisa in eastern Uganda. To build the solar product adoption history, the purchases of participating households were tracked from the year the household reported acquiring its first solar product until early 2017. We recommend to continue to track purchases of solar products by these approximately 500 users and to collect data on the life of solar products to review the NPV analysis. An additional survey will help create a four-year adoption history for most users (and an adoption history of over four years for those who bought their first solar product before 2015).

Through the first two surveys we noticed that affordability is constraining the adoption of large and complex SHSs. Purchases of single-light systems and small plug-and-play multi-light kits were mostly driven by need, availability, retailer proximity, and effective direct marketing by retailers. Income and affordability, while always important, did not appear to be the primary limiting constraint, given the flexible financing provided for systems with more than one light. Because affordability is a barrier to the purchase of larger systems, it is crucial to determine how many Level 1 and Level 2 users[16] were able to subsequently adopt larger systems now that more time has passed, and determine the choices and constraints that were in play for users who were unable to obtain larger SHSs.

IMPLEMENTING SIMILAR STUDIES IN OTHER REGIONS

These results represent findings from two regions in Uganda characterized by having a greenfield market for off-grid solar products, significant penetration of mobile money, unsubsidized fossil fuels (e.g. kerosene for lighting), high usage of traditional fuels before purchase of solar products, and expensive and unreliable grid electricity. In a different market context, different results may hold. Caution needs to be observed before transferring findings of any energy study from one geography to another. For example, it is possible that we would find different results in Kenya, where the off-grid solar energy market is more mature, or in India, where energy subsidies on fuels and electricity tariffs for domestic and agricultural consumers have distorted the energy markets for decades, and where levels of mobile money penetration in rural areas are relatively low.[17] It would be worthwhile to investigate the adoption patterns for solar energy products in a market which has historically been distorted by subsidies, and where these recent policy-led events have created a complex and poorly understood dynamic for off-grid solar products. To build a more general and context-independent understanding of the adoption of solar products in off-grid settings, a multi-country analysis is needed.

NEXT STEPS

Given the success of the effort and additional questions raised from the first round of research, the UNCDF CleanStart programme and Schatz Energy Research Center are currently conducting a third round of surveys with the same respondents. This research will be done in close collaboration with the Uganda Solar Energy Association (USEA). The objectives of this follow-up study are: (i) to continue to track user adoption histories to gain an advanced understanding of how solar product adoption processes play out over a longer time period; (ii) to unpack the reasons for customer dissatisfaction with flexible financing terms and their unwillingness to opt for financing options for subsequent purchases of solar products; and (iii) to investigate the impact, if any, on the use of mobile money caused by the Government of Uganda's introduction of a transaction tax on mobile payments for goods and services in 2018.

16 See 'Methodology' in Section 3 for a definition of the levels of solar energy access of users as defined in the study.

17 Admittedly, the Indian government has been phasing out the subsidies, installing meters in previously unmetered rural households and increasing rural electrification efforts by expanding the utility grid at breakneck speed.

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ANNEX 1: ASSUMPTIONS FOR ESTIMATION OF DAILY ENERGY SERVICE LEVELS

We used the energy service available from the use of the solar products owned by participating households in watt-hours per day (Wh/d) as a parameter to indicate their level of solar energy access. To compute this for each of the time periods, 2014 and before, 2015, 2016, and until February in 2017, we consolidated details of the types of off-grid solar energy products households acquired during each period. This included products that were purchased by them, gifted to them, or given for free as demonstration and promotion units by solar companies. We used a combination of product specifications, self-reported data on appliance use from the surveys, product sales data from SunnyMoney, Greenlight Planet, Fenix International and SolarNow, and informed assumptions to estimate the daily energy service for each product owned by a household.

To calculate the daily energy availability, in cases where the wattage rating of the solar module was known, we used the module size, an estimate of the average daily solar resource in the region, and an assumption that 50 percent of the energy generated by the solar module was available for use by the household. Most products fell into this category, as we often knew the product make and model and/or had obtained information about the solar module power rating during the interview. When making these calculations, we used an annual average solar resource of 5.1 $kWh/m^2/day$ based on data reported in Urmee et al. (2016). We used a value of 50 percent for the system efficiency; this is a conservative figure that considers losses from battery charge/discharge, resistance in circuits and connectors, and the inability to capture all the electricity generated by the solar module due to maximum power point losses and the fact that the battery is sometimes fully charged.

There were some cases where the module size of a product was not known but the purchase price was available. In these cases, we used information about typical system pricing to estimate the module size. We then used the method described briefly above to calculate the approximate daily energy service. In a smaller number of cases, neither the module size nor the price was known, but the end-user household had reported information about the appliances that were powered by the system. In these cases, we made a bottom-up estimate of the daily available energy based on assumptions about the power consumption and hours of use for each appliance. See Table 2.1 for a list of assumed power consumption and use rate values for the respective appliances in the study.

All appliances are assumed to be DC appliances, except for laptops or in cases where an AC appliance or use of an inverter was specified in the survey response. When making assumptions for calculation inputs, we used conservative assumptions to avoid overstating the level of household energy service. The assumptions associated with appliance power consumption were informed by advertised values for the listed appliance or other similar models (when available), prior laboratory and field measurements of appliance power use for similar appliances, and estimated values reported in the literature (Solar Energy International, 2004; 2017). In cases where daily appliance use values were needed for a bottom-up estimate of daily energy availability, the daily appliance use values were based on estimated appliance use for similar household systems in the study where module size and appliance information were known, field observations over several decades related to off-grid solar use in African countries by one of us (A. Jacobson), and literature sources such as Lighting Global (2013) and Phadke et al. (2015).

Table 2.1. Assumptions for estimating daily energy service derived from off-grid solar products in cases where a bottom-up calculation based on appliance power consumption and daily use was required

APPLIANCE WATTAGE ASSUMPTIONS	
LED light bulb or tube	1.5W
Solar lantern	0.24W
Radio	3W
TV	30W
Computer/laptop	40W (assumed an 11” mini-laptop)
Music system/woofer	10W
Water pump	50W
Flat iron	150W
Refrigerator	45W (assumed to be a small 35l DC fridge)
Appliances in stationery shop	31.5W (assumed to be 1 light and a printer of 30W)
Salon machines	10W (assumed to be 1 light and an 8.5W electric shaver)
LED light in a torch	0.2W
Millet grinding mill	100W
DVD player	30W
OTHER ASSUMPTIONS REGARDING ESTIMATION OF POWER NEEDED TO CHARGE AN APPLIANCE	
Size of panel bought to increase capacity of existing solar system	10W
Appliances bought to expand the number of end-uses powered by an existing system	100W (assumed to be a CRT TV and small additional AC loads)
Number of mobile phones that a commercial phone charger can charge simultaneously	8
APPLIANCE USAGE/ENERGY ASSUMPTIONS	
1st light in system	4.0 hours/day
2nd and 3rd light in system	3.0 hours/day
4th to 6th light in system	2.0 hours/day
7th + light in system	1.0 hours/day
Energy required to charge a mobile phone	5.3Wh based on a 3.7Wh battery and 70% charging efficiency
Radio	5.0 hours/day
TV set	4.0 hours/day
Iron	0.3 hours/day
Fridge	6.0 hours/day
Home mobile phone charger	1.0 hours/day
Commercial mobile phone charger	8.0 hours/day
Music system	2.0 hours/day
Shaver	3.0 hours/day
Laptop	2.0 hours/day
Water pump	6.0 hours/day
Torch	1.0 hours/day
Lantern	3.0 hours/day
DVD player	2.0 hours/day

ANNEX 2: ASSUMPTIONS FOR NET PRESENT VALUE ANALYSIS

Table 3.1. Assumptions for NPV analysis

ASSUMPTION HEAD	ASSUMPTION VALUE	NOTES ON ASSUMPTION/DATA SOURCE
COMMON ASSUMPTIONS FOR TYPICAL USERS ACROSS THE THREE LEVELS OF SOLAR ENERGY ACCESS		
Interest rate for savings deposits in commercial banks	18.96%	Average of 2015 and 2016 savings deposits interest rate published by Bank of Uganda
Discount rate	5.45%	Average of 2015 and 2016 annual headline inflation published by Uganda Bureau of Statistics
Withholding tax on interest payments as a percentage of the gross amount of the interest paid	15%	Published by Uganda Revenue Authority
Annual Energy, Fuel and Utilities (EFU) inflation for the year ending December 2016	3.7%	Average of 2015 and 2016 annual EFU inflation, published by Uganda Bureau of Statistics
Exchange rate: UGX per US$	3,333	Average official mid-rate published by Bank of Uganda for 2016
ASSUMPTIONS SPECIFIC TO TYPICAL USERS AT LEVEL 1		
Investment in solar product: Price of lantern	$9.90	Product price data provided by SunnyMoney
Median monthly savings from use of lantern	$2.80	Self-reported data by respondents
Small 4-light kit user: Price of single light with mobile charging	$24.20	Product price data provided by SunnyMoney
Median monthly savings from use of single light with mobile charging	$2.80	Self-reported data by respondents
ASSUMPTIONS SPECIFIC TO TYPICAL USERS AT LEVEL 2		
Investment in solar product: Price of 17W 4-light kit	Cash price: ~ $206 Credit pricing: Down payment $25.5; Monthly payment $12.15; Repayment period 18 months	Product price data provided by Fenix International
Median monthly savings from use of 17W 4-light kit	$3.70	Self-reported data by respondents
Investment in solar product: Price of 10W 3-light kit	Cash price: ~ $156 Credit pricing: Down payment $18; Monthly payment $9.90; Repayment period 18 months	Product price data provided by Fenix International
Median monthly savings from use of 10W 3-light kit	$3.60	Self-reported data by respondents

ASSUMPTIONS SPECIFIC TO TYPICAL USERS AT LEVEL 3		
Investment in solar product: Price of 50W 3-light home system	Cash price: $375 Credit pricing: Down payment $72; Monthly payment $19.50; Repayment period 24 months	Product price data provided by SolarNow
Median monthly savings from use of 50W 3-light home system	$6	Self-reported data by respondents
Investment in solar product: Price of 50W 3-light + 19” TV home system	Cash price: $546 Credit pricing: Down payment $117; Monthly payment $28.5; Repayment period 24 months	Product price data provided by SolarNow
Median monthly savings from use of 50W 3-light + 19” TV home system	$5.25	Self-reported data by respondents